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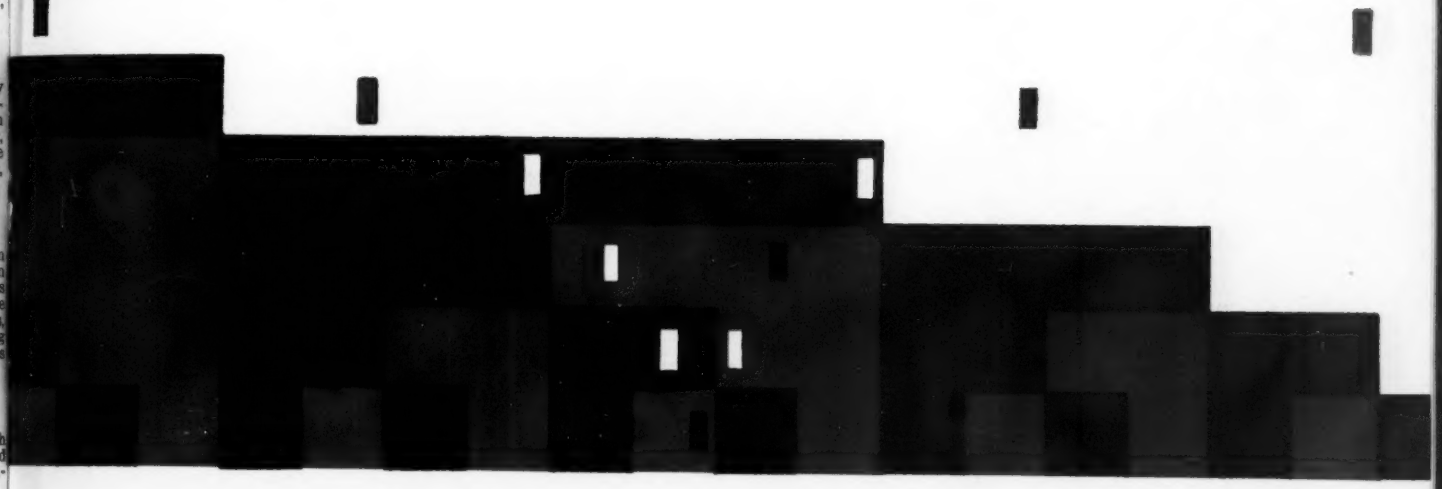
ELECTROMECHANICAL
components & systems DESIGN

JUNE 1959



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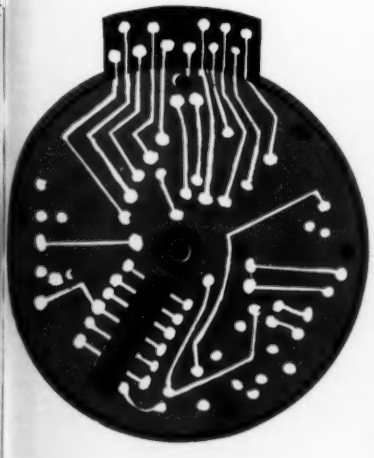

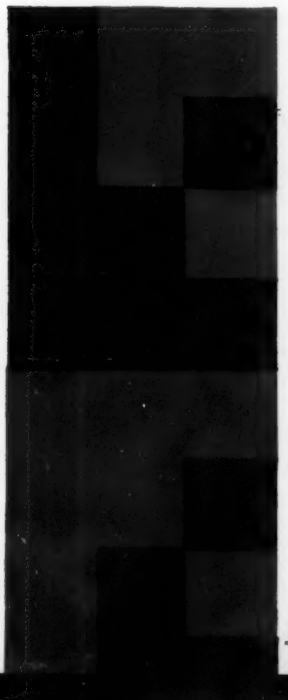

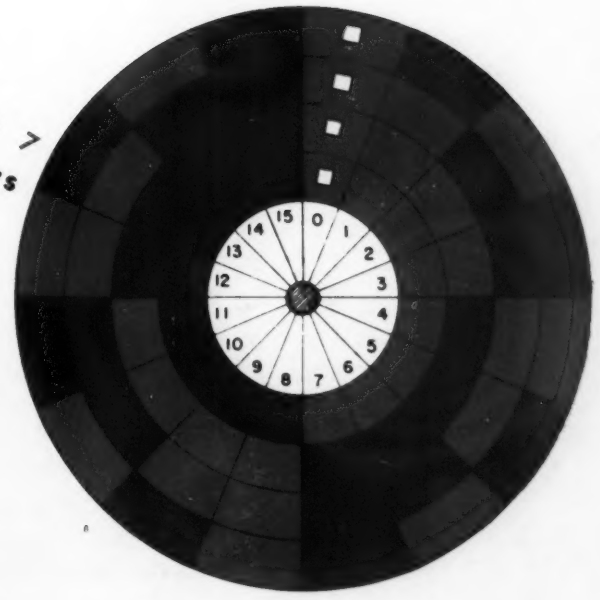

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The Sourcebook of Design Ideas in Applied Electromechanics

VOL. 3, NO. 6

JUNE 1959

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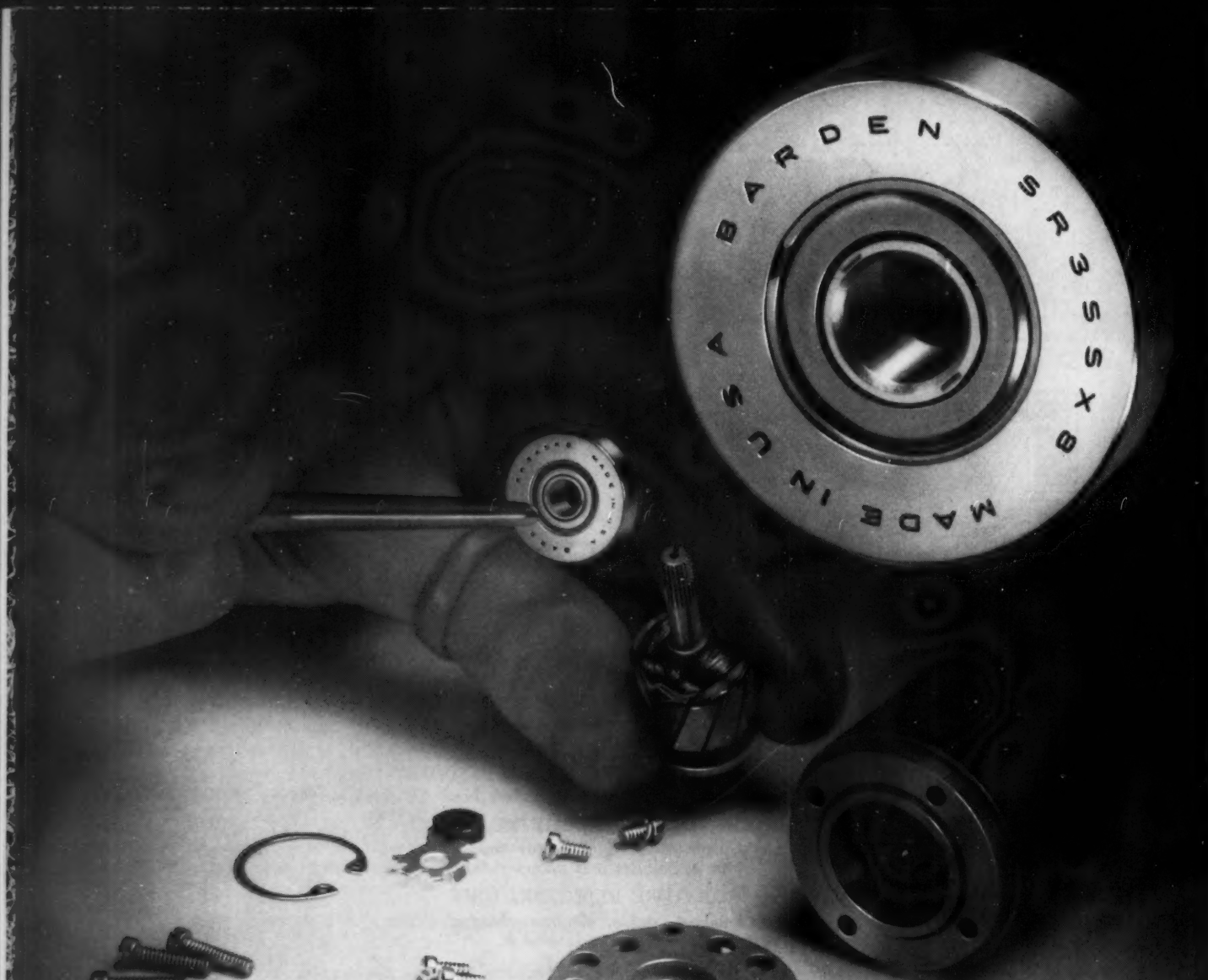

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LETTER FROM THE PUBLISHER

Dear Reader:

For almost a year the Editors of ELECTROMECHANICAL DESIGN have been gathering and summarizing data on electromechanical components and systems for you. They are about to sit down and make up a schedule for 1960.

The objective of these digest presentations have been to simplify your job of locating and specifying the proper component or system for a given application. Now you can help us do an even better job for you by letting us know those areas in which you would like our editorial staff to concentrate. In effect, you have at your command a staff of engineers that will research, on an industry-wide basis, an entire area of engineering know-how and availability.

We would like to know specifically what subjects you would like to have our editorial staff cover in these future issues. To those of you who may have missed some or all of our previous digest supplements, here is what we have done in the past:

1958—October	Instrument Servo Motors
December	Precision Potentiometers
1959—February	Electromagnetic and Potentiometer Transducers, Part I
March	Environmental Design and Testing, Part I Electromagnetic and Potentiometer Transducers, Part II
April	Sensitive Relays
May	Connectors and Fasteners—Part I Electromagnetic and Potentiometer Transducers, Part III

This month we are covering Part I of Analog-Digital Converters and Part II of Environmental Design and Testing. Here is the schedule for the rest of the year.

1959—July	Analog-Digital Converters, Part II Connectors and Fasteners, Part II
August	Switches, Part I
September	Fractional Horsepower Motors
October	Switches, Part II
November	Sub System Packages, Part I
December	High Temperature Components, Part I

Note that once we initiate a Components or Systems Digest on a subject, we maintain a continuing coverage on it either with addendum pages or supplemental parts.

What we cover in 1960 will be influenced by those of you who write in suggesting specific topics. Of course, we would like you to detail your requests; however, all you need do is tear out our prepaid Reader's Service card from the front or back of the book and scrawl across it one, two or more topics you would like to see us cover. We have used small sampling techniques to measure those areas in which you have problems, but feel that an open letter to you gives us an opportunity to sample all of you who have found these digests useful and time saving. Won't you take a few minutes to help us help you?

Cordially,

Harold G. Buchbinder
Publisher

MACHINE TOOL COMPONENTS

Where Do We Go From Here?

The size and complexity of today's machine tool designs are such that the control circuitry has physically outgrown the tools they control. Almost all machine tool builders have long been aware of these growing pains as their customers relinquish greater amounts of floor space to equipment of more questionable reliability. Improvements in machine tool controls are mainly attributable to the ability of the builders to borrow components from those industries fortunate enough to have benefited from intensive development efforts. Last April at the 23rd Annual Machine Tool Electrification Forum, sponsored by Westinghouse Electric Corp. in Buffalo, N.Y., machine tool designers and users cocked critical eyes at the status of their industry.

WHAT'S WRONG WITH MACHINE TOOL COMPONENTS

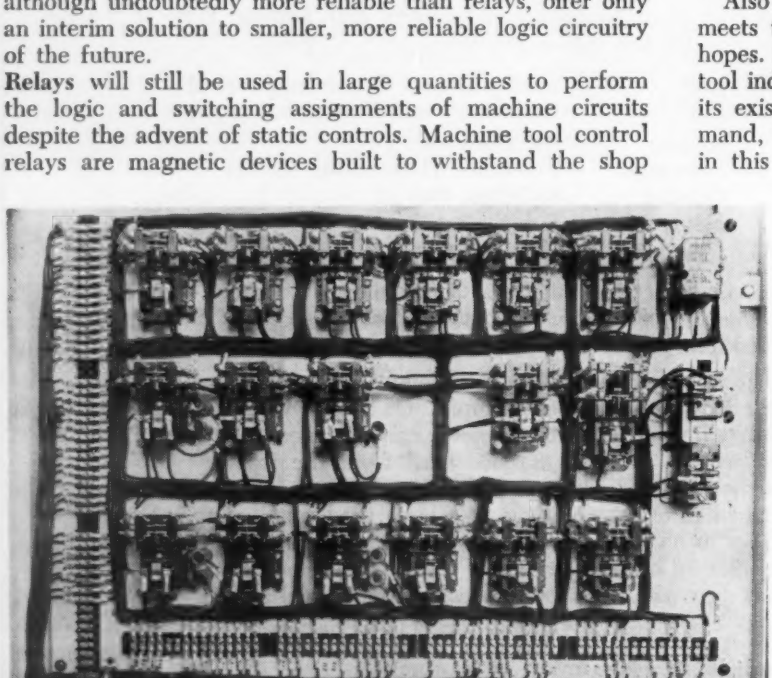
Here's what Mark H. Sluis of Pratt and Whitney, West Hartford, Conn., had to say about machine tool components:

Static controls are a much heralded means of eliminating a large source of control unreliability—the relay. In a majority of control circuits a single input to a logic circuit demands many output actions. Static controls are economical only where there exists a large ratio of inputs to outputs with a nominal amount of logic circuitry between. At that, there is little, if any, financial advantage to be gained in the initial installation. At best, static controls although undoubtedly more reliable than relays, offer only an interim solution to smaller, more reliable logic circuitry of the future.

Relays will still be used in large quantities to perform the logic and switching assignments of machine circuits despite the advent of static controls. Machine tool control relays are magnetic devices built to withstand the shop atmospheres, to minimize contact failure and, in general, to perform "reliably" for an unknown lifetime characterized by the metallic clanking of their heavy armatures. (Often, sheer mass appears to be capable of beating the structure to an untimely death.) They are equipped with screw termination (in some cases rather inaccessible) to provide a pressure contact in accord with specifications. In their day, these relays were an asset to heavy-current, high-voltage switching, but with the incorporation of electronics this emphasis has all but disappeared. In many instances heavy vibration, created by relay actuation, vibrates screw terminals loose or, worse, disengages two mating mechanical parts. Poor contact or no contact is a frequent ill when employing this type of relay in an electronic circuit, switching millivolt signals at milliampere levels. Contact failure at this level might be excusable when considering the structure of these relays; unfortunately, however, it is not limited to low power levels. Often a 110-volt potential is supported across a supposedly closed set of contacts.

A new relay is definitely needed, one which would have much more reliability in its contacts as well as in its terminations (a point too often ignored), longer life expectancy, faster action, and above all, smaller size as a few of its requirements. A line of relays which meets many of these requirements has been used in the telephone industry for some time. They have found favorable reception in more than one machine tool builder's plant.

Also on the market today is a mercury-wet relay which meets the life and reliability requirements of our fondest hopes. Note, however, that it was *not* built for the machine tool industry; in fact, many tool people are still unaware of its existence. Because of the lack of competition and demand, its price will also deter many of its possible users in this field.



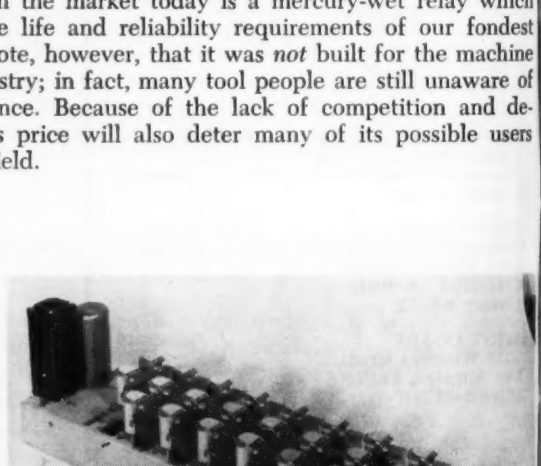


Fig 1 Comparison of the compactness of a group of telephone type relays and a comparable group of machine tool relays. In addition to compactness, the telephone relays also offer a greater number of contacts available per unit.

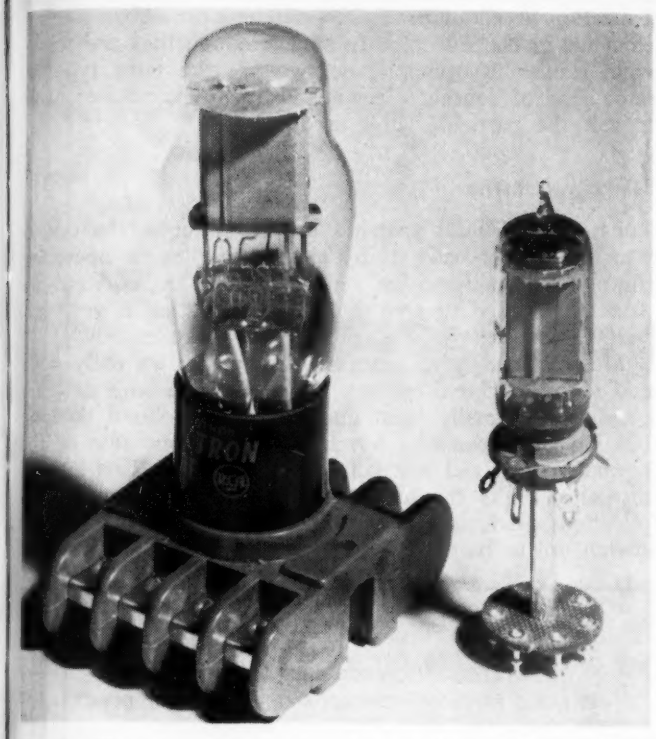


Fig 2 These two tubes and sockets perform the same function: left, screw termination; right, solder termination.

Vacuum tubes and thyratrons are finding increasing use in modern logic and switching circuitry. The industrial or "ruggedized" versions of radio tubes are of stronger internal construction and presumably give longer life than their ancestors. Main neglect has been the socket. Where a normal (radio-type) socket requires solder connections, an industrial socket has been developed to provide screw termination, Fig. 2. This is done at four times the panel area of a solder-type socket and at no improvement in reliability. Sockets require a redesign or at least a review of existing designs to determine their suitability for machine tool use.

Connectors are finding more and more use in machine tools and are adaptable to plug-in assemblies. Modular construction using plugs and receptacles has much space-saving ability as well as being simple to service by direct replacement. Connectors for machine tool applications have been blackballed more or less by the industry and its customers. Use of these devices adds to connection points and thus increases the chances of poor contact. Nevertheless, plugs and receptacles have reached a high level of reliability particularly in better quality lines. Not all connectors, even though they are AN approved, are identical in construction. Resilient inserts and spring-loaded closed-entry female sockets are preferable for extreme reliability. These units are used by the thousands in planes and missiles, systems which demand the utmost in performance integrity.

Connections. An electrical device of any sort is only as good as its terminations. Where the connection into a circuit is intermittent or subject to failure, performance of the device is hampered severely if it does not render the complete system inoperative. For years machine tools have thrived on the use of screw terminations and for the same number of years these same screws have been vibrating loose. After all, *how* tight is a tightened screw?

Soldering techniques have been considered too risky and have been used only for mass produced products like radios and television, from which maintenance people make a respectable living. Despite the general unfavorable attitude toward soldering, much soldering is being forced upon the industry by the construction of available components.

Recent developments have brought pressure connections using tapered mating parts. These terminations are to be commended since they far exceed the performance of screw terminals. Vibration does not loosen them but, best of all, the fact that they are inserted with a spring-released tool assures uniform insertions that are 100-percent proper. Another advantage is that termination density is increased.

Transistors have firmly entrenched themselves in electronics. Power ratings at present are insufficient, however, to permit us to consider its exclusive use as a switching element in machine tool control. In the limited applications to which transistors have lent themselves so far, their questionable temperature reliability and life expectancy have served as serious deterrents.

Two years ago Westinghouse introduced the NOR circuit in which transistors are used as multiple-input switching devices. This circuitry should find in the future a multitude of logic switching applications. Future progress in this field should be of major interest to the machine tool builder, since it could lead to tremendous space savings.

Push buttons, selector switches, lights and meters must be small enough to be manageable. Still they must be oiltight to comply with specifications. Available industrial lines are oversized, without exception; there is a very specific need in the industry for smaller devices of this category. Some oiltight devices are of inferior design, if at all obtainable: To name a few, they include potentiometers (with reliable looking features), selector switches with more than 3 or 4 positions, meter movements and standard 2- or 3-pole outlets.

Starters are the most space consuming of all the devices comprising a control circuit. It is, of course, of utmost importance to have a low-voltage switching level for motor currents and to adequately protect these motors from electrical damage. Since the inception of the idea of across-the-line motor starting many years ago, progress in design has been at a virtual standstill. Recent developments improving the commercial practicality of controlled rectifiers have suggested a means of doing away with the starter. Before not too many years more, semiconductors will conquer this field. There are also available high-voltage, high-current vacuum switches which might suggest an intermediate method of motor control. The stagnancy that has characterized recent years should provide fertile territory for new ideas in this field.

Transformers present an unexplored area for size reduction with the availability of improved magnetic materials and recent developments in toroidal winding techniques. The bulkiness of control transformers is a large factor in determining cabinet size. Here again, dogged adherence to screw or stud termination has manifested the need for large terminal boards in the case of multitap reactors. Constant voltage transformers are also particularly large, in addition to having rather poor performance; their harmonic content and resultant distortion of wave shape is intolerable in many applications.

Rectifiers. Tremendous advances in the semiconductor field have at least resulted in some well-deserved payoffs in space, reliability and price in the machine tool industry. There's no such problem as selenium aging to contend with and there need be no hesitance in applying rectifiers in high ambient temperatures. Direct-current power has been made more readily available than ever through the use of silicon rectifiers. Proper application of these rectifiers will lead to long and trouble-free performance.

Wire. Above all, there remains a question as to the advantage of using a No. 14 wire with 3/64-inch insulation (capable of carrying 20 amperes at 600 volts) to carry two volt-amperes as is true in 90 percent of control circuits. Too, we have thermoplastic insulated wire which is unsuitable for soldering but which offers oil resistance. Since only a fractional part of wire used is not already inside an oilproof enclosure, must this requirement for oil resistance be met twice?

Shielded wire or cable is unmentioned in the specifications, yet to purchase shielded cabling from standard stock to meet wire size, insulation thickness and oil resistance requirements is a near impossibility. Multiconductor cables consisting of dozens of No. 16, 2/64-inch insulated wires no longer offer the flexibility they were intended to have, nor is the bending radius of a 2- or 3-inch metal-enforced wire housing something to be overlooked.

For these reasons it would be far better to take a second look at the wire types and size requirements of various applications and cut some of the oversize safety margins closer to reality.

LIMIT SWICHES VS. PROXIMITY SWITCHES

As machine tools become increasingly automatic and complex, contact-making sensing devices such as limit switches and proximity switches are used in ever greater numbers. Since today's machines are quite expensive, and excessive down time cannot be tolerated, requirements for the sensing devices are increasingly difficult to meet. John M. Morgan, Jr., manager of the Cincinnati Milling Machine Company's Development Research Department pointed out that the importance of obtaining better sensing devices is borne out by a number of recent surveys which show that faulty input devices and, primarily sensing devices, are one of the major causes of machine down time. Although limit switches represent the majority of sensing elements, Morgan noted that proximity switches are now being used in more and more applications. Limit switches and proximity switches, Morgan pointed out, both have their advantages and disadvantages. Here's his approach to the problem of selecting one over the other for any specific application.

IDEAL CONTACT-MAKING SENSING DEVICE

A splendid solution to our problems would be to have a single device in which all necessary and desirable characteristics are combined and thus to have the ideal contact-making sensing device. To meet most requirements this ideal device should be: completely reliable, simple, positive, fail-safe, foolproof, accurate, fast operating, small in size, low in cost, easy to mount and wire and suitable for use in all environments. In addition, it should have an adequate number of contacts, adequate power handling capacity, snap-action, small differential, low operating force, the ability to sense without contact and should provide ample overtravel.

Although certain applications require additional features such as multiple contacts, these can be considered as special cases and are thus not included for consideration.

Unfortunately, no ideal contact-making sensing device is yet available. Limit switches meet many of our requirements, and so do proximity switches, but neither is a universally applicable device. Even with the degree of standardization that characterizes limit switches, it is necessary to use different limit switches for different jobs to obtain best results. At present, there has been no standardization at all of proximity switches, for either sensing elements or control units. In fact, although they are somewhat similar in principle, no two use the same type or same size of sensing element. Provisions must be made to suit the particular unit used.

LIMIT SWITCHES

Practically all limit switches are based upon the operation of a set of contacts by a lever or plunger operating through a "load-and-fire" mechanism. The load-and-fire principle is used to give the snap action that is very important to achieve long contact life and accuracy.

Most limit switches are provided with a normally open and normally closed contact. Some precision limit switches provide a normally open and a normally closed contact, but have one common terminal between one side of the normally open and normally closed contacts. This lack of flexibility limits the use of these switches for many applications, paricularly when the extra contacts of the limit switch are to be used for safety interlocking reasons.

TABLE I

A COMPARISON OF CHARACTERISTICS OF VARIOUS TYPES OF CONTACT-MAKING SENSING DEVICES

	Mechanical Limit Switches	*Vane-Operated Limit Switch*	*Proximity Switches*
Reliability	2	1	1
Simplicity	1	1	3
Positiveness	1	2	3
Fail-Safe	1	2	3
Foolproof	1	2	3
Accuracy	1	2	3
Fast Operation	3	2	1
Size-Sensing Unit	2	3	1
Size-Total	1	2	3
Cost	1	2	3
Mounting & Wiring	1	1	2
Suitable for Adverse Environment	3	2	1
Adequate Number of Contacts	1	3	2
Power Handling Capacity	1	3	2
Snap Action	1	2	2
Small Differential	1	2	3
Low Operating Force	2	1	1
Sensing Without Contacts	—	2	1
Provision for Overtravel	2	1	1

Limit switches are simple, positive, accurate, easy to mount and wire, and low in cost. For most applications they have adequate contacts, adequate power handling capacity, snap action and small differential. When properly applied mechanically, and without excessive load on the contacts, limit switches will give a high degree of reliability.

The main limitation of limit switches is in certain applications where presence of chips and coolant cause failure of the limit switch. They cannot be used where it is necessary to sense parts without physical contact. They should not be used in applications such as counting, where extremely fast operation is required, and where life is measured in 100 millions of operation. Limit switches can be and have been used as input devices in static control systems. In such applications, care must be taken to insure that the limit switch contacts are suitable for low power level operation.

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COMPONENTS DESIGN

PROXIMITY SWITCHES

Most proximity switches are based upon use of a sensing element which operates upon a magnetic principle and a control or power unit which, mounted on the panel, operates the external sensing device and gives corresponding output signals. Most proximity switches can use either a relay for output or can generate signals to be fed into static control elements. Outstanding feature of proximity switches is their ability to sense the presence of a part or operating element without actual physical contact. In general the part to be sensed must be of a ferrous material, although some proximity switches can also sense nonferrous objects. Although their operating range is generally from a few thousandths of an inch to one inch, proximity switches can be obtained with operating ranges up to a distance of several feet.

One manufacturer of proximity switches can supply very small sensing elements for use where space is restricted. One unit, 2-¼ inches long and designed for mounting in a ⅝-18 thread hole, is designed for use while submerged or on machines using cutting oils or coolants. When properly applied, proximity switches are quite reliable. They can be extremely fast in operation, and, feeding into static elements, are ideal for counting operations. Most of the sensing elements are made to be suitable for operation in adverse environments.

In general, however, proximity switches are not as simple and positive and not as fail-safe as limit swiches. They normally have a larger differential, and do not have the snap action to be expected from a limit switch. In cost, proximity switches are 6 to 10 times more expensive than limit switches.

Some types of proximity switches require shielded leads between the sensing element and the control unit. This makes wiring somewhat more difficult, particularly when the length of lead between the sensing element and the control unit is important. Proper precautions must be taken at junction points in the shielded cable such as occur at terminal boards.

VANE-OPERATED LIMIT SWITCHES

This relatively new device is neither a true limit switch or a proximity switch. It is designed to give leverless operation with less cost and fewer mounting problems than proximity switches. It does not require a separate power supply and is designed for long operating life.

The switch is energized by the passage of a soft steel vane through a recessed slot in the switch. The vane, attached to the mechanism to be controlled, disturbs a magnetic field balance and causes two small contacts to close or to open when the vane passes through the slot. The contacts, which are sealed, are located between two permanent magnets. Normal stray magnetic fields, metallic objects such as tools, or presence of magnetic dust and chips in the slot will not cause false operation.

When properly applied, the vane-operated limit switch will give reliable operation. It is simple and easy to understand, and, like a limit switch, is relatively easy to mount and wire. Most of its characteristics fall in between the limit switch and proximity switch.

Major limitation of the vane-operated limit switch is that it can be provided with a single contact only which must be specified, when purchased, as normally open or normally closed. The contact used is designed for long life when operating a low coil-current relay, but is somewhat inadequate in power handling capacity.

FAIL-SAFE FEATURES

The importance of the ability of a sensing device to fail-safe varies, of course, with the application. If the limit switch or proximity switch is being used in a "counting" or "permissive" application, failure of the device to function properly is normally less detrimental than if the device is being used to stop the motion of a machine slide. Most careful consideration must be given to the selection of devices for applications in which wrecks could occur or safety of the operator could be imperiled by faulty operation of the sensing device.

To obtain the maximum degree of safety, circuits are generally arranged so that all relays and solenoid valves will open when the "stopping" operation is to take place. The chances of a relay sticking closed or a solenoid valve failing to open are considered much less likely than failure of a relay coil or contact and/or failure of the solenoid coil. In other words, we depend upon the simplest type of mechanical operation to give the most positive type of action.

TABLE II

CRITICAL COMPONENTS IN CONTACT-MAKING SENSING DEVICES

Mechanical Limit Switch	Contacts Springs Seals
Vane-Operated Limit Switch	Contact Seal
Proximity Switch (With Electronic Tubes and Output Relay)	Sensing Element Tubes Relay Coil Relay Contacts
Proximity Switch (With Static Elements and Output Relay)	Sensing Element Relay Coil Relay Contact

The relative costs of limit switches, the vane-operated limits switch, and proximity switches are shown in Table III. This indicates that in general proximity switches cost between 6 and 10 times as much as limit switches. Cost of the vane-operated limit switch lies in between.

TABLE III

COST OF CONTACT-MAKING SENSING DEVICES

DEVICE	COST
Mechanical Limit Switches	$10 — $20
Vane-Operated Limit Switch	$40
Proximity Switches	$100 — $150

In applications of this type a slide is normally stopped by opening the normally closed contact of the limit switch. This may operate the corresponding solenoid valve directly or through relays. Assuming that the limit switch is properly applied and protected, and that the contacts are operated positively by the lever arm, this system is considered to be the most reliable method for obtaining trouble-free operation.

Proximity switches normally depend upon the picking up of a relay to give the same contact opening provided by the limit switch. In some cases, reverse operation can be obtained. Even so, if tubes are used and a tube fails, this may cause erroneous operation and failure to stop at the required point. Since tubes can fail either way, and can be either conducting or nonconducting after fail-

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ure, it is normally not considered good practice to use any device containing electronic tubes in critical applications. Although this has been done in some critical applications, it is generally because there is no practical alternative.

The use of proximity switches with static elements that feed static control equipment may improve this condition. Since most of these devices can fail in either mode, careful consideration must be given to their use in critical applications.

TABLE IV

LIFE OF CONTACT-MAKING SENSING DEVICES

Device	Life in Millions of Operations When Controlling		
	00 Relay	Small Relay	Static Control
Mechanical Limit Switch	5+	30+	50+
Vane-Operated Limit Switch	5+	30+	250+
Proximity Switch	—	30+	500+

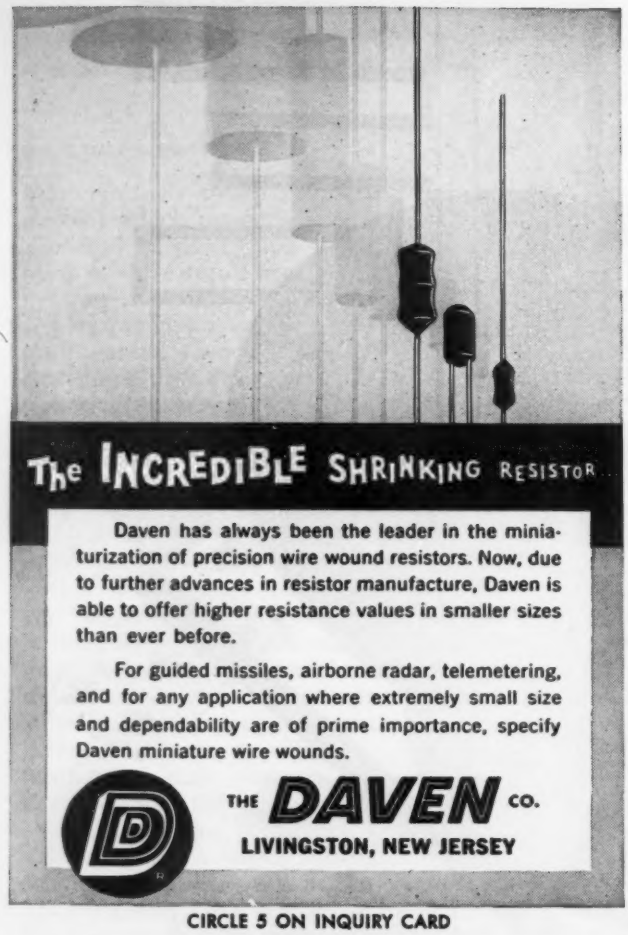
It has been said, and rightly so, that to obtain trouble-free operation is worth the cost of more expensive components. But, even so, when a machine tool requires a large number of sensing devices, their cost becomes a very important consideration.

This difference in cost also gives rise to an interesting question: Could a much-improved limit switch be built and sold to the machine tool industry at a cost of $50 instead of $20? Many machine tool engineers have considered this as a definite possibility, but have yet to convince electrical manufacturers of the merits of their case. Electrical manufacturers state that they must build limit switches which are competitive in price and for general industry use, or they cannot sell them. It is somewhat puzzling that this argument does not apply in the case of proximity switches.

One of the most important features of any device is its operating life. It is difficult to give any specific answer on life, since so many factors affect the operating life. Quite obviously, improper application of any device will result in short life.

In the listing of critical components of the various types of sensing devices of Table II, where it is assumed that the proximity switches use an output relay, we see that the contacts are the most common limiting factor in all devices. The life of these contacts is affected by this external load; in Table IV we present an approximation of the life of various devices with different external loads.

Considering only this feature, the most logical answer would always appear to be use of a static-type proximity switch feeding into static-type elements. In some applications this is true, but is not feasible in other applications because of the cost and other factors already discussed. It is interesting to note that reports from users indicate that proximity switches are not proving to be as reliable as they theoretically should.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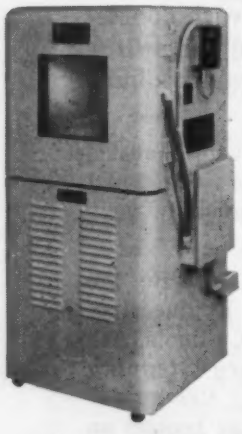

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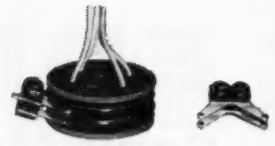

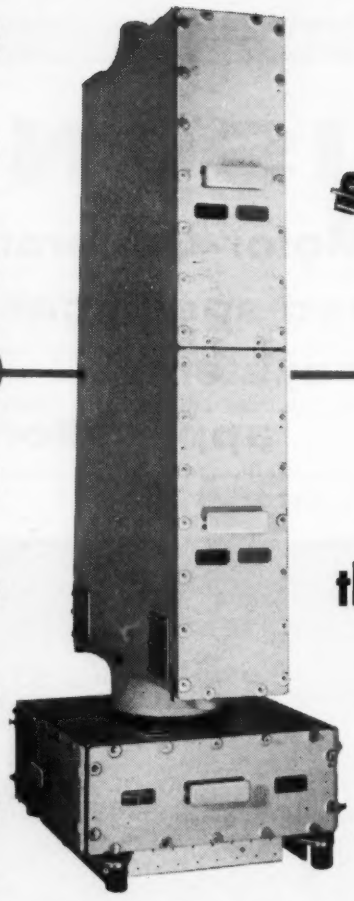

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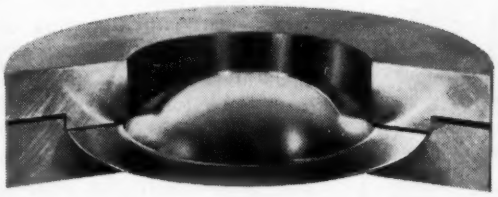

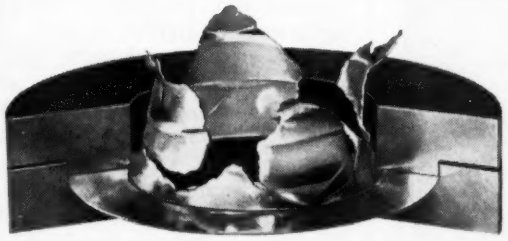

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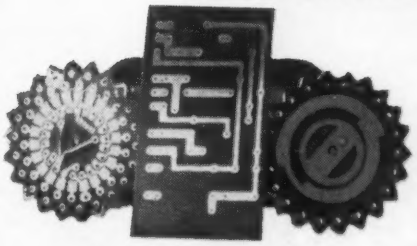

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MATING CLAMP

Internal Cylinder Clamp Increases Strength Of Thin-Walled Sections

An internal clamp design for thin-walled cylinders that increases the stiffness and strength of mated cylindrical sections is now in use at Aeronutronic Systems, Inc., Newport Beach, Calif. Designed by Joseph Hirsch, the basic system consists of a mating clamp inserted internally in the cylinders to be joined. The clamp is a one-piece spring ring having two unequal raised surfaces which lock into two corresponding indentations in the cylinders.

For disassembly the snap ring can be released by closing a pin-pointed pliers set in grooves in the snap ring. A fabric (elastomer) material seals the system and provides a spring force necessary for rigidity as well as easing tolerances in manufacture. Mr. Hirsch states that this method of attaching cylinders has applications for attaching pipes, "T" connections for pipes, corners and elbows, rocket-body attachments, structural pipe connections and other types of cylindrical attachments. The new design was developed because outside locking attachments could decrease the strength of the sections to be joined. Outside attachments generated buckling loads on the external wall of the cylinder while the internal attachment places the skin of the cylinder in tension.

For the clamp to fail, the raised surface would have to fail in shear. For this reason the height of the raised surface can be small and the clamp can be used with walled material. For pressure pipe, no decrease in pipe strength occurs if the raised surfaces are equal to or less than one-half the thickness of the pipe. The new mating clamp can be made integral with one of the cylinders and can be so designed that it can have the same inside diameter of the basic pipe.

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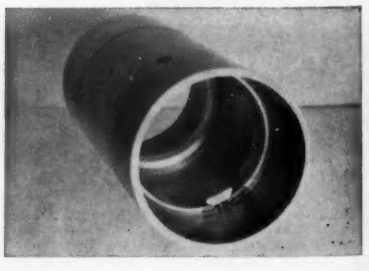

Fig 3 Internal view of assembled cylinders showing internal mating clamps with wedge not tightened into position.

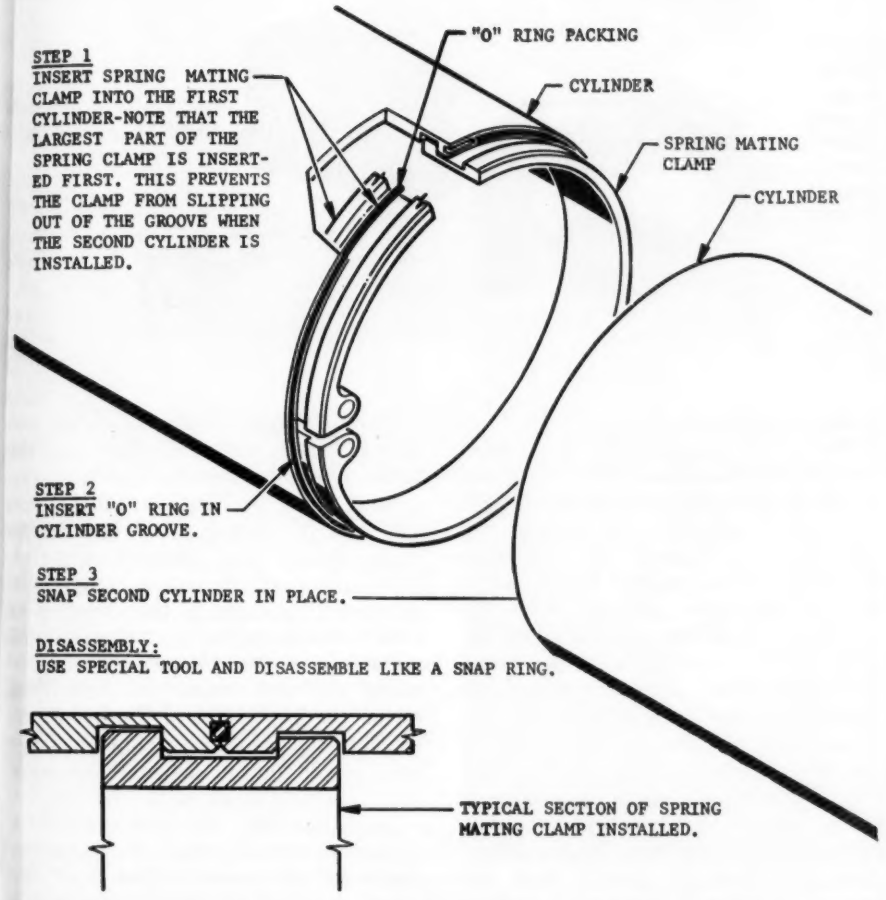
"O" RING PACKING
CYLINDER
SPRING MATING CLAMP
CYLINDER
STEP 1
INSERT SPRING MATING CLAMP INTO THE FIRST CYLINDER-NOTE THAT THE LARGEST PART OF THE SPRING CLAMP IS INSERTED FIRST. THIS PREVENTS THE CLAMP FROM SLIPPING OUT OF THE GROOVE WHEN THE SECOND CYLINDER IS INSTALLED.
STEP 2
INSERT "O" RING IN CYLINDER GROOVE.
STEP 3
SNAP SECOND CYLINDER IN PLACE.
DISASSEMBLY:
USE SPECIAL TOOL AND DISASSEMBLE LIKE A SNAP RING.
TYPICAL SECTION OF SPRING MATING CLAMP INSTALLED.

Fig 1 Cutaway view shows basic clamping method. Advantages of this method is ease of assembly and disassembly, lower cost and higher strength in mating thin-walled cylinders.

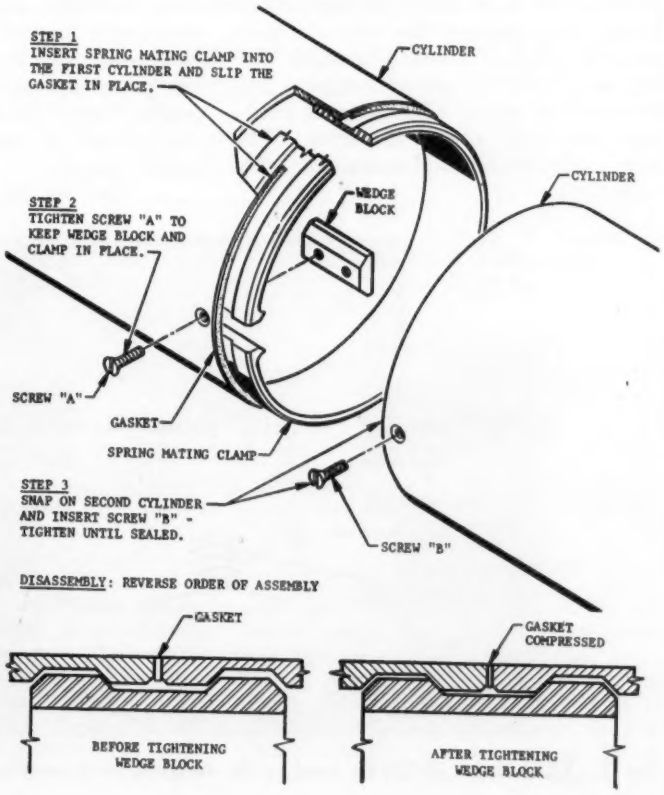

Fig 2 Modification of the basic design in Fig. 1 utilizes a wedged block that locks the clamp into position. In this design the raised surfaces have sloping sides. Cylinders are easily separated upon release of the wedge.

Reusable Silver-Zinc Primary Battery

A new type of silver-zinc battery combines the recyclability of a secondary battery, the fast activation of a primary and the high power output of the silver-zinc system. Called the Yardney Silvercel, it can produce outputs as high as 70 watt-hours per pound and has an activated stand time of more than two months without capacity loss. With a peak of 17 cycles already reported, it can be used 11 to 14 times and can be activated for immediate use by manual filling thus eliminating the extra weight and size involved in an automatic activation system. Since the battery can be recycled, reliability can be established prior to actual use in the application. Yardney Electric Corp., New York City.

Circle No. 183 on Inquiry Card

B+ Switching Component

Commutating switch handles B+ switching at approximately 150 volts D.C. Unit operates from a 6 volt D.C. supply to provide 6 rps pole speeds. Its switching section consists of a single pole with 12 make-before-break contacts with a maximum of 5 percent shortening time between contacts. A hermetically sealed case has one DCH-37P-001 for the single loads and one MC14H-8-3PN connector for the motor leads. Approximately 2¾" x 2¾" x 6", the case weighs only 2 lbs. This switching component is capable of operating at −40F at altitudes of 200,000 ft., while undergoing vibration spectrums represented by 20g from 20 to 2,000 cps. Instrument Development Laboratories, Inc., Attleboro, Mass.

Circle No. 223 on Inquiry Card

WORTH FILING

Synchro and Rotary Components

Here's one of the neatest and most useful compilations of complete electrical characteristics, mechanical characteristics and drawings for all types of synchros, size 8 through 22, that has come across our desk in some time. Similar information is given on a wide line of precision computing resolvers and linear transformers (induction potentiometers). A large section of the book is devoted to complete electrical and mechanical information on servo motors and motor generators, sizes 8 through 11, with speed torque curves. Also, geared motors and size 8 d-c motors.

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For Your Copy: Circle 217 on Inquiry Card

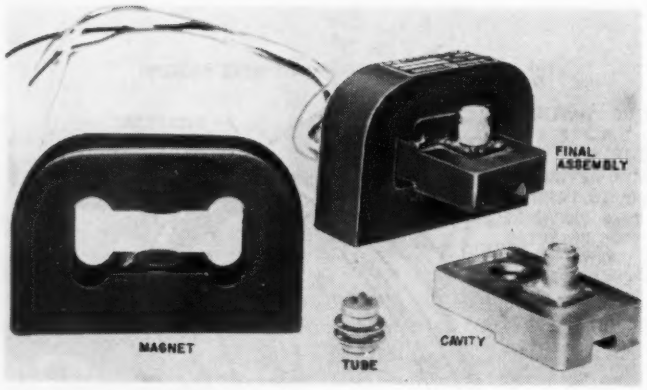


Fig 1 The Z-5300, a wide band general purpose package, delivers a minimum of 2 watts over the 2200 to 3850 magacycle frequency range. A plot of the typical power output shows that the frequency is essentially a linear function of the applied voltage. The efficiency and power input plot shows that the efficiency varies inversly with frequency while the power input varies directly with frequency. It is this combination that enables us to design for the flat power output response.

VOLTAGE TUNABLE MAGNETRON

Smaller VTM

by

Dr. Myron Weinstein

Power Tube Dept.,

General Electric Co.

The sophistication of electronics systems is increasing every day and this puts many of the problems and challenges up to those who develop the basic components. There is a continual demand, especially from those who develop airborne or space borne systems, for oscillators and amplifiers that are more efficient, smaller, more rugged and more versatile. They would also like these basic components to possess new and unique characteristics heretofore unavailable in a microwave device that would enable them to develop new types of systems or improve existing system. The Voltage Tunable Magnetron is an important new member of the microwave tube family that fulfills the demands mentioned above. This new basic component has many outstanding features that make it attractive for widespread use in airborne receivers and transmitters.

Voltage Tunable Magnetron package consists of a VTM tube sub-assembly, an RF circuit or cavity and a magnet that are properly aligned and locked together into an integral unit with DC input leads and an RF output connector. (Fig 1) It is a device that can be electronically tuned over very wide tuning ranges; the electronic tuning, essentially linear as a function of the anode voltage, is accompanied by high efficiency operation and a power output response that can be made quite flat over extended frequency ranges. The tube sub-assembly, quite small, (a penny will cover any view) is made of few parts with rugged ceramic and metal construction.

The small rugged tube has important implications from the standpoint of electronic performance as well as mechanical and size and weight considerations. (1)A small RF slow wave structure will not support higher modes and is thus more desirable from the standpoint of discouraging spurious signals, (2)the few parts with reasonable dimensions are instrumental for consistency and repeatability of performance from tube to tube. One of the most striking features of the VTM tube sub-assembly is its versatility. It has a unique characteristic that may be termed its "power out-tuning range" constant. Moderate power over extended electronic frequency tuning ranges may be obtained or higher power over more modest tuning ranges is also available by merely designing the external circuit or cavity to provide the proper impedance to the tube. In each case the product of the electronic tuning range and the power output is approximately equal. The different packages that make use of the same VTM tube sub-assembly demonstrate this versatility.

The packages illustrated have several things in common. They use the same tube sub-assembly and the same magnet. (Fig 2) The same techniques are used for aligning and locking the tube, circuit and magnet together. Main point of departure, physically, for these packages is the circuitry or cavity structure that provides the impedance over the operating frequency range for the tube. As mentioned earlier the impedance of the circuit determines the operating frequency range and power output as well as some other characteristics of the package.

In general the tube sub-assembly is approximately ½ order of magnitude improved in power output and efficiency over VTMs offered heretofore, and also features packaging techniques that make possible small, light units that have a built-in heat sink. The various packages offer a variety of features, such as wide tuning range, high power–narrow band and low noise, low power operation–features that will enable system designers to utilize this new device in many interesting and useful places.

Circle No. 123 on Inquiry Card

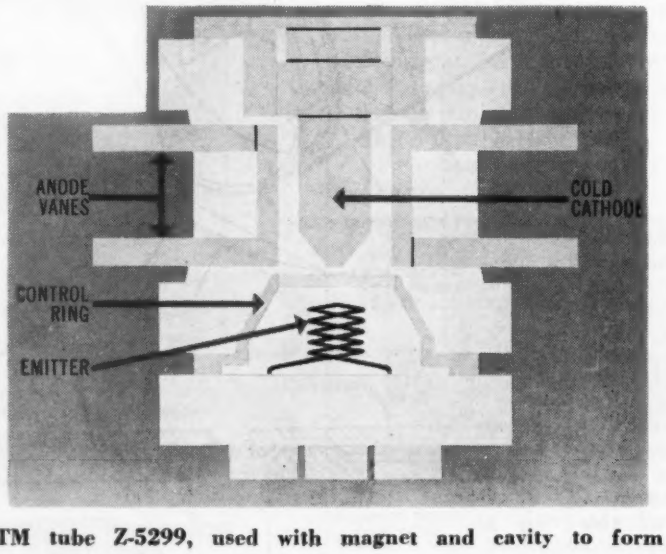
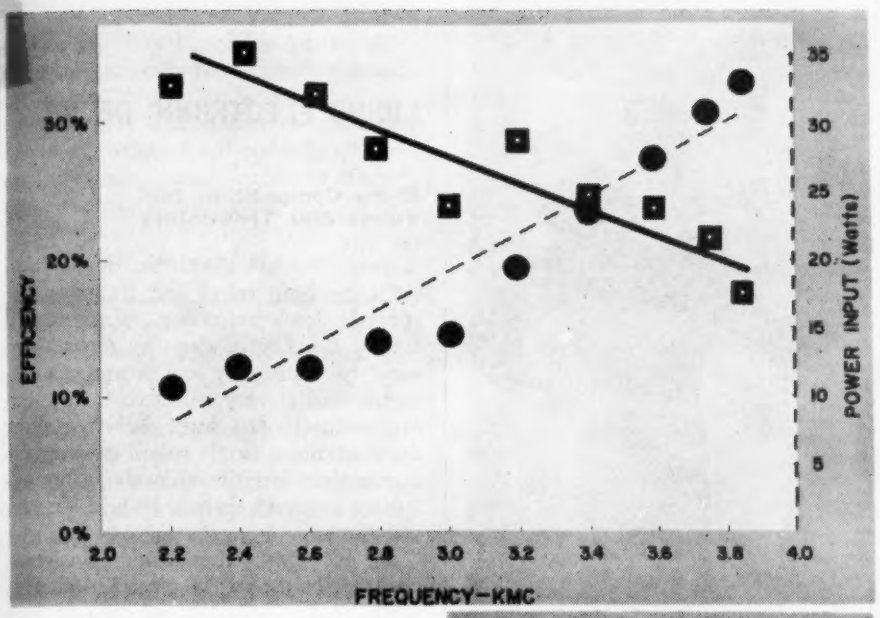


Fig 2 VTM tube Z-5299, used with magnet and cavity to form package.



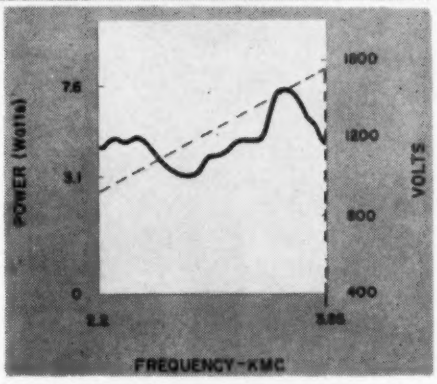


Fig 3 The Z-5321, a narrow band, high power VTM package, trades tuning range for power output; this package is capable of 10 watts minimum over 200 Mc centered at approximately 3000 Mc. The efficiency is approximately 35 to 40%. Considerably higher power outputs than 10 watts have been obtained from this unit. The package has also been pulsed on and off by a voltage pulse applied to the control ring. Unit weighs 3.1 pounds and has an operating voltage of 1250 volts at center frequency. While the Z-5321 covers a 200mc frequency range centered at 3000 mc and are presently available, narrow band packages centered throughout the S-band frequency band are certainly within the capability of the tube subassembly and present development state of the art.

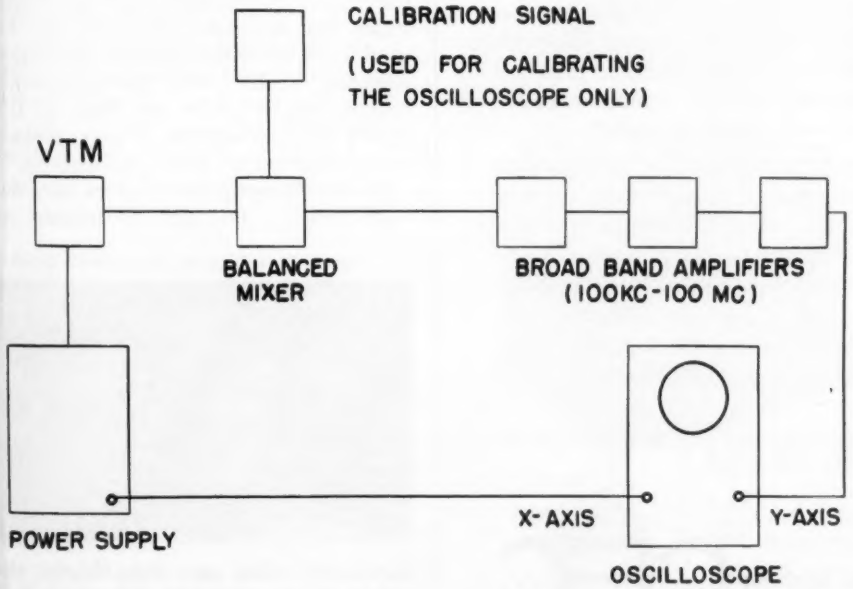


Fig 4 In the noise measuring circuit, the output of the tube is put into a broadband balanced mixer. The tube is swept across the tuning range and the output from the mixer is put through amplifiers that pass 100 kc to 100 mc. This output is then rectified and displayed as a function of the frequency over which the unit is tuned. A calibrated signal from a signal generator is used to establish the reference level. Circuit dynamically measures all the peak noise in the very wide 100 kc to 100 mc band about the carrier. Specification requires a noise output 55 db minimum below the carrier signal.

A Logical Deduction

Because ordinary magnetically-regulated power supplies are **too sluggish** to handle load and line transients,

Because NJE refused to be satisfied with such performance, and developed, back in 1956, a **fundamentally superior circuit,**

Because this thoroughly proven circuit uses the speed and power-gain of a transistor amplifier to force rapid response from the magnetic amplifier,

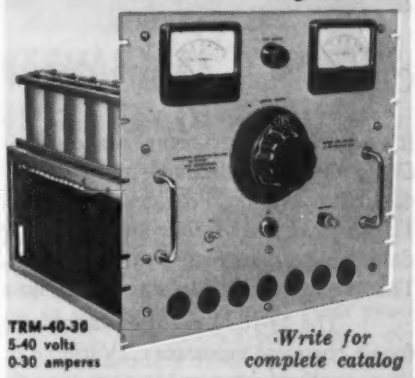
Because the transistors are never in the power path, but handle low-level signals only,

Because this transistor-magnetic—"TRM"—circuit retains the reliability and economy of magnetically-regulated supplies, but greatly improves speed of response (15 millisec. typical) widens operating range (8:1 typical) and tightens regulation (0.1% typical),

Because TRM supplies can be "zero-lagged" against line and load transients,

It follows that NJE TRM is your **best buy** in a magnetically-regulated power supply!

QED... choose NJE



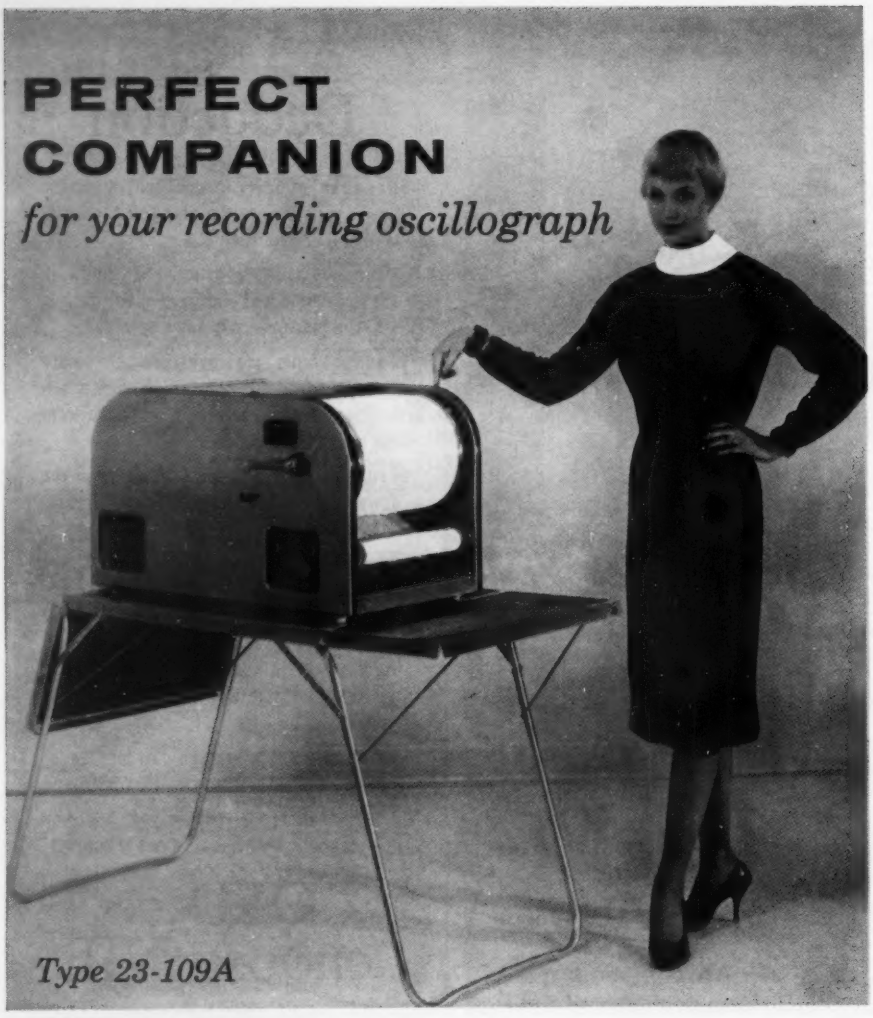
TRM-40-30
5-40 volts
0-30 amperes

Write for complete catalog

MODEL NUMBER	OUTPUT RANGE VOLTS	AMPERES
TRM-28-30	24-32	0-30
TRM-28-60	24-32	0-60
TRM-28-120	24-32	0-120
TRM-40-15	5-40	0-15
TRM-40-30	5-40	0-30
TRM-40-60	5-40	0-60
TRM-40-120	5-40	0-120
TRM-80-7.5	10-80	0-7.5
TRM-80-15	10-80	0-15
TRM-80-30	10-80	0-30
TRM-80-60	10-80	0-60
TRM-160-7.5	20-160	0-7.5
TRM-160-15	20-160	0-15
TRM-160-30	20-160	0-30

NJE CORPORATION
345 Carnegie Avenue, Kenilworth, New Jersey
CH 1-1500 TWX - Roselle, N. J. 51 FAX - FFP

CIRCLE 13 ON INQUIRY CARD



CEC's *new improved* OSCILLOGRAM PROCESSOR

It's a portable "darkroom" for on-the-spot processing of oscillograph records. Completely self-contained, motorized for automatic operation, and designed for daylight operation. Provides developed, dry, and ready-to-use oscillograms quickly. The Processor saves time and expense by permitting prompt checks of recorded data to determine results *fast*. This often eliminates necessity of additional tests. The Processor is ideal for field use; no external water supply is needed.

The 23-109A features variable bath temperature control to accommodate future chemical processes... Variable drum-temperature with *thermistor* sensing element eliminates troublesome open thermostats... Adjustable magazine accepts record widths to 12 inches... New design permits side-by-side processing of two narrow rolls... Simplified threading allows anyone to process records perfectly every time.

Spare magazines are available for rapid sequence work. Ready-mixed chemicals are packaged for complete filling of processor tanks. Available for 115-or 230-volt, a-c operation.

For complete information, call your nearest CEC sales and service office or write for Bulletin CEC 1537-X1.

Electro Mechanical Instrument Division CEC

CONSOLIDATED ELECTRODYNAMICS

360 Sierra Madre Villa, Pasadena, California

CIRCLE 14 ON INQUIRY CARD

LIQUID ELECTRONIC DEVICE

More Competition for Tubes and Transistors

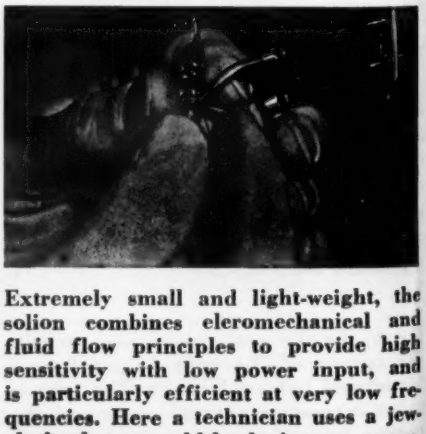
A new "liquid" electronic device outperforms both tubes and transistors in special low-frequency applications. Called the solion, the tiny circuit element has extremely low power requirements and is very sensitive to low energy stimuli. In some low-frequency applications, a single solion can replace a complete circuit assembly, often resulting in more than a 10-fold size reduction.

In electron tubes and transistors, electrons transport the electrical charge, while in the solion a solution of ions —hence the name—carries the charge. An electrochemical reaction at the electrodes causes a current change in an external circuit. Electronic designers now have another choice of dynamic circuit elements.

An integrating sound exposure meter, the size of a pack of cigarettes, indicates one possible use of a visual readout solion integrator, and is an example of many new dosimeters made practical by the solion.

An operating electrical readout integrator demonstrates the simplicity, low drift rate, and linearity of such equipment. In addition to use as an integrator, error signal accumulator, and control element, National Carbon Co., Div. of Union Carbide Corp. states that the integrator can also be used as an amplifier with flat frequency response in the very low frequency range—from 2 cycles per hour to 0.5 cycles per second and it may replace a d-c amplifier in some applications.

Solion pressure transducers can detect pressure changes as minute as



Extremely small and light-weight, the solion combines eleromechanical and fluid flow principles to provide high sensitivity with low power input, and is particularly efficient at very low frequencies. Here a technician uses a jeweler's glass to weld lead wires on a complete solion integrator assembly prior to encapsulation in a plastic resin.

three dynes per square centimeter (approximately 0.001 inches of water). Other similar units have been designed as vibration meters or accelerometers. More complex solions can be made to carry out mathematical operations, giving rise to such possible uses as analog computers, data processing equipment and inertial guidance systems.

Circle No. 107 on Inquiry Card

Weatherproof, Shock-Resisting Photorelay

Low-cost, electric eye housed in a weather tight and shock-resistant enclosure is a simple light sensing control that withstands the effects of dust, moisture, shock, vibration and other adverse environmental conditions. Using a solid-state photocell, automatically triggers on-off and go-no-go circuits at predetermined light levels. It is sensitive to 10 foot candles. The Model R-Ch operates on 60-cycles, 115 volts AC. It uses single-pole, single-throw relay contacts rated at 5 amperes at 115 volts AC. Power consumption is 2.5 watts. Berkeley/Dynamics, Berkeley, Cal.

Circle No. 248 on Inquiry Card

Printed Card Connectors

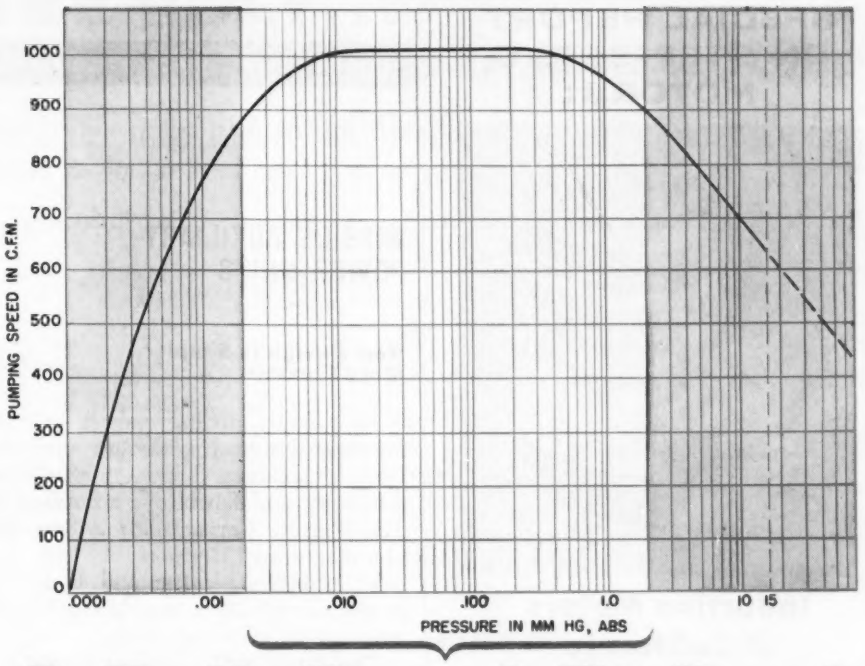
New type connector has two rows of taper pin terminals linked mechanically and electronically for use with AMP 53 taper pins. Positive re-entrancy of the male pin is assured each time by the "Molding Assist Closed Entry." Ideal for critical environmental conditions and extremes of military applications, these connectors are available in total contacts of 7, 11, 15, 19, 23, and 32. U.S. Components, Inc., New York, N.Y.

Circle No. 229 on Inquiry Card

6 Amp Diffused Junction Silicon Rectifiers

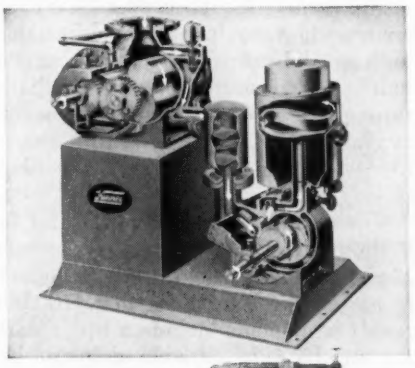
New series of diffused junction silicon rectifiers provide currents up to six amperes over an inverse voltage range from 50 to 500 volts. Designed for miniaturized airborne power supplies, electrical instrument testing, oscilloscopes and other power supply requirements, these units are operable at diode base temperatures up to 150C. To provide optimum reliability over their working temperature range, these hermetically-sealed units have all-welded construction completely free from flux material. Each unit is nickel-plated to provide minimum contact resistance and prevent corrosion. Internat'l. Rectifier Corp., El Segundo, Cal.

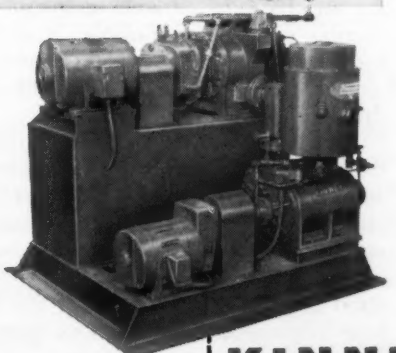
Circle 196 on Inquiry Card



Do You Use Vacuum In This Range?

From millimeters to microns . . . in this region the significant economy of the KINNEY KMB Mechanical Booster Pump is self-evident, as shown by the performance curve above. And, this high efficiency is doubly attractive because these KINNEY Pumps provide *clean, dry* Vacuum . . . no backstreaming . . . automatic operation . . . no stalling problems from gas bursts.





Kinney®

MECHANICAL BOOSTER HIGH VACUUM PUMPS

The KINNEY KMB Pumps have proven themselves in the most difficult applications. They feature high pumping speed in the low micron range and their design provides for addition of interstage cold traps with minimum plumbing or other complications. Their performance, even where outgassing of materials renders other pumps inoperative, stamps them as the major contribution of the decade in High Vacuum service.

KMB 1200 with free air displacement of 1230 cfm. Other models provide pumping speeds from 30 cfm to 5100 cfm.

WRITE for Bulletin No. 3180.1 It's FREE

KINNEY MFG. DIVISION
THE NEW YORK AIR BRAKE COMPANY
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Please send me copy of Bulletin No. 3180.1 describing KINNEY KMB High Vacuum Pumps.

Name_____

Company_____

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City_____ Zone_____ State_____

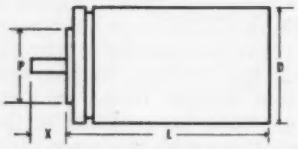
CIRCLE 15 ON INQUIRY CARD

SPECIAL REPORT ON STEP-SERVO MOTORS:

Induction Motors of California Offers Step-Servo Motor Line

A full line of step-servo motors, sizes 5, 8, 11, 15 and 23, designed for digital-to-analog conversion in 45° increments up to 120 pulses per second, are manufactured by Induction Motors of California. The motors are available with impedance of 15 to 300 OHMS and voltage range of 20 to 50 VDC. Motors operate over a range of −55°C to +125°C and meet environmental requirements of MIL-E-5272B and MIL-E-5400. Stainless steel construction is used, and no mechanical detents are employed.

GENERAL SPECIFICATIONS FOR STEP-SERVO MOTORS



I.M.C. P/N	Dim. in Inches D	L	P	X	Rotor Inertia GM-CM²	Min. Holding Torq. Oz.-in.	Max. Watts Per φ
005-801	.500	1.20	.375	13/32	0.50	0.5	8
9708-024	.750	1.09	.500	11/32	0.65	0.8	10
011-859	1.062	1.36	.625	3/8	0.65	1.4	15
9711-007	1.062	1.76	.625	3/8	2.5	1.4	15
9711-050	1.062	1.78	.625	3/8	2.5	1.2	15
9711-053	1.062	1.36	.625	3/8	2.5	1.0	15
9715-001	1.437	1.75	.875	3/8	2.5	1.8	25
023-801	2.250	1.75	2.00	5/8	5.0	3.0	50

Information on cost, delivery, or additional technical information, as well as information on synchro components and solenoids, is available when requested on your company letterhead.

Induction Motors of California

DIVISION OF
INDUCTION MOTORS CORPORATION, N.Y.
6060 Walker Avenue, Maywood, California
LUdlow 3-4785
Representatives in principal cities

CIRCLE 16 ON INQUIRY CARD

MISSILE AUXILIARY POWER UNITS

New Design Is Simpler, More Flexible

A new model auxiliary power unit for missiles, designed with "an unprecedented maximum degree of reliability, simplicity and flexibility" according to The Garrett Corporations AiResearch Manufacturing Division of Los Angeles, supplies electric and hydraulic power to operate a missile's guidance and control systems.

The latest APU eliminates external plumbing, cuts the number of valves to less than half that originally used on AiResearch APUs now being manufactured for the Nike Hercules. It starts instantly and has better serviceability with approximately half the parts used on present production units.

Designed to operate on ethylene oxide, it may also be used with hydrazine and, with minor modifications, with a solid propellant. Thus, the new unit provides maximum flexibility through use of proven components available now, with the advantages of using other energy sources with adaptations.

The current model supplies 5 hp for a duration of 7½ minutes at specific load schedule. Its altitude range is from sea level to more than 100,000 feet. Components include a squib starting mechanism, variable delivery hydraulic pump, accumulator, reservoir, fuel tank, manifold valve assembly, alternator, speed control and turbine drive unit.

The squib start initiates ethylene oxide decomposition by igniting a small replaceable solid propellant charge, which provides instantaneous starting capability without rearming the gas generator. The charge has been sized to assure acceleration of the turbine to rated speed within two seconds at ambient temperature as low as −65F.

The variable delivery pump delivers required system flow at a pressure range of 2880 to 3200 psig. A new design utilizes a single valve block to house all valves necessary for proper operation of the unit. Of the approximately 18 valves previously required, the manifold valve assembly reduces this number to 7.

A new alternator for the APU has been designed which is a two-phase, permanent magnet, pad-mounted machine sized for existing requirement. One phase provides 30 volts A.C. for direct rectification to D.C. for operation of a fuel control valve. The second phase provides 120 volts a-c for missile lift-off signal and the turbine frequency sensor.

The turbine is not subjected to adverse effect of step load changes resulting in better speed regulation. The turbine assembly has been redesigned to incorporate a pad-mounted, variable displacement pump and alternator, providing ease of replacement in the field. The APU weighs 85 lbs. less fuel and oil. It measures approximately 30″ long, 12″ wide and 15″ high.

Circle No. 120 on Inquiry Card

Military D.C. Power Supply Eliminates "Overshoots"

A new addition to the transient-free line of magnetic amplifier-transistor regulated d-c power supplies, the 6-15 volt and 0-5 ampere output militarized model M-1360 meets MIL Specs MIL-P-6457A, MIL-G-008512, and MIL-E-4970 for Sheltered Applications. New unit features advantages of two types of amplifiers: excellent transient regulation of a transistor amplifier and the high efficiency and reliability of a magnetic amplifier. Line dynamic regulation is less than ±0.050 volts for step change of 10 volts in the a-c input of 115 volts, 60 cycles, while load dynamic regulation is less than ±0.2 volts from no load to full load. Automatic current limiting circuitry provides protection against dangerous overloads and dead short circuits. Perkin Engineering Corp., El Segundo, Cal.

Circle No. 225 on Inquiry Card

Low-Cost Moisture-Proof Timing Motor

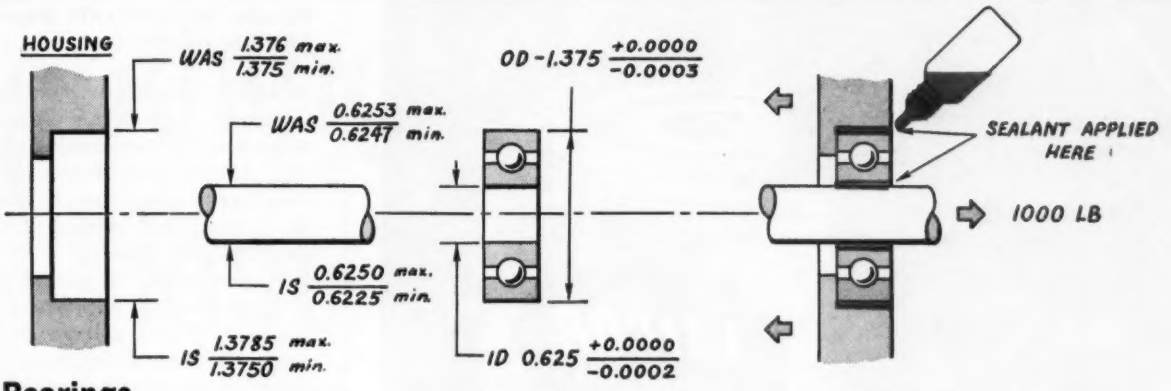
A new, low cost, moisture proof timing motor deisgned for chart drives, timing devices, and other similar applications in the instrumentation and commercial field, offers an extremely good protective surface against highly corrosive atmospheres found in various chemical and processing plants.

The timing motor itself is a heavy duty, permanent synchronous type with a guaranteed torque at 30 ounce-inches at 1 rpm. Synchronization is maintained over a range of 103 to 132 volts a-c. The MP11 is available for 120 or 240 volt operation at 50 or 60 cps. Standard shaft speeds are available between 1/60 rpm and 60 rpm. Haydon Div. of General Time Corp., Torrington, Conn.

Circle No. 250 on Inquiry Card

SIMPLIFY ASSEMBLY...
Retain parts on shafts with slip fit and Loctite

Designing with liquid LOCTITE eliminates press fits, shrink fits, broaching, knurling, keyways, set screws and pinning ... provides easier tolerances ... cuts rejects and rework.

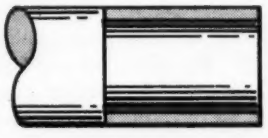


Bearings

LOCTITE Sealant replaced press fit, opening up tolerances .002 inch on shaft and housing. Rejects were cut from 8% to 1% and rework from 20% to 0! Bond to inner race withstands 1000 lbs. thrust ... equal to the best press fit. Slip fit with LOCTITE gives more uniform retention ... eliminates fretting damage due to loose "press fit" or bearing distortion resulting from tight press fit ... assures better shaft alignment. Easier tolerances speed assembly.

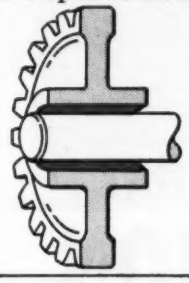
Hardened Sleeves

Eliminates shrink fit ... mounts hardened sleeve without pulling temper.



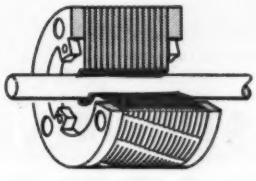
Gears and Pulleys

Eliminates broaching, knurling, shaft distortion. Easier gear replacement.



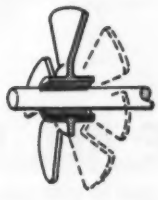
Rotors

Eliminates shaft distortion and resulting regrinding & straightening.



Fans

Eliminates set screws ... no amount of vibration will loosen part.



LOCTITE Sealant is easy to apply... simple to automate

LOCTITE is a one-component liquid with the unique property of converting to a tough plastic when confined between close fitting metal parts. It does not air dry. It does not require mixing with a catalyst and will not spoil on standing in a storage vessel. It comes fully prepared ... stores for years ... hardens only when treated parts are assembled. It forms a tough seal that resists heat, oil, water, all common solvents. Parts treated with LOCTITE can be disassembled by ordinary methods.

LOCTITE Kit No. 10-10

Contains 10 grades of Loctite Sealant specially put up to assist designers in determining proper grade and use of Loctite in product development and for general experimental work. By selection of proper grade, the designer can apply a predetermined amount of locking torque.

Write for literature and free sample.

LOCTITE® SEALANT AMERICAN SEALANTS CO. 109 Woodbine St., Hartford 6, Conn.

CIRCLE 17 ON INQUIRY CARD

THE ALL PLASTIC VALVE THAT

DEFIES CORROSION

VALCOR's all plastic, corrosion-resistant solenoid valve, SV-5100 series, is the only solenoid valve that has no metal contact with the fluid—ever. Specifically designed to handle most of the corrosive media so widely used in industry, VALCOR's new, all plastic solenoid valve will, in many cases, outlast stainless steel valves 100 to 1.

If you have a corrosive media problem, from sulphuric acid solutions to citrus juices, try this new VALCOR valve on your toughest application. Prove for yourself how this new valve defies corrosion. List prices start at $8.50.

IMPORTANT: Hundreds of other valve variations, in design and pressure ratings, are inherent in this new SV-5100 series. By incorporating some of the very newest engineering and chemical formulas, we can offer valve variations designed to meet almost any corrosion problem you might be faced with.

Write today for new catalog sheet. For specific information, please send us pertinent application details.

VALCOR ENGINEERING CORP.
5374 CARNEGIE AVENUE, KENILWORTH, NEW JERSEY

VALCOR
SOLENOID VALVES

CIRCLE 18 ON INQUIRY CARD

Missile And Aircraft Barometric Altitude Controller

A light weight Barometric Altitude Controller with infinite resolution provides two distinct modes of operation with a very high degree of accuracy, even under the extreme vibration and shock conditions typical of missile and aircraft environments.

"Unengaged", it provides effectively instantaneous altitude or pressure information as a voltage and shaft position, thereby functioning as a precision altimeter. "Engaged", by either manual or self-engagement, it provides precise information on altitude deviation for flight control use. No clutching or spring null return elements are used. Transition between modes is smooth, without "jump" signals.

While higher altitude and temperature ranges can be provided, the standard operating range is from sea level to 100,000 feet with temperature errors held to ±3 feet between −55C and +71C. Vibration and shock effects along the sensitive axis are less than one foot per "G". Velocity errors are effectively zero when "engaged" and under 50 feet for rate of climb of 180,000 ft/minute when "unengaged". In the "unengaged" mode, linearity and hysteresis are held to ±0.25% or 100 feet, whichever is greater, up to 80,000 feet altitude. When "engaged", linearity over ±500 feet excursion is ±3% and hysteresis under 3 feet upon return to "engage" altitude. General Controls Co., Glendale, Cal.

Circle No. 247 on Inquiry Card

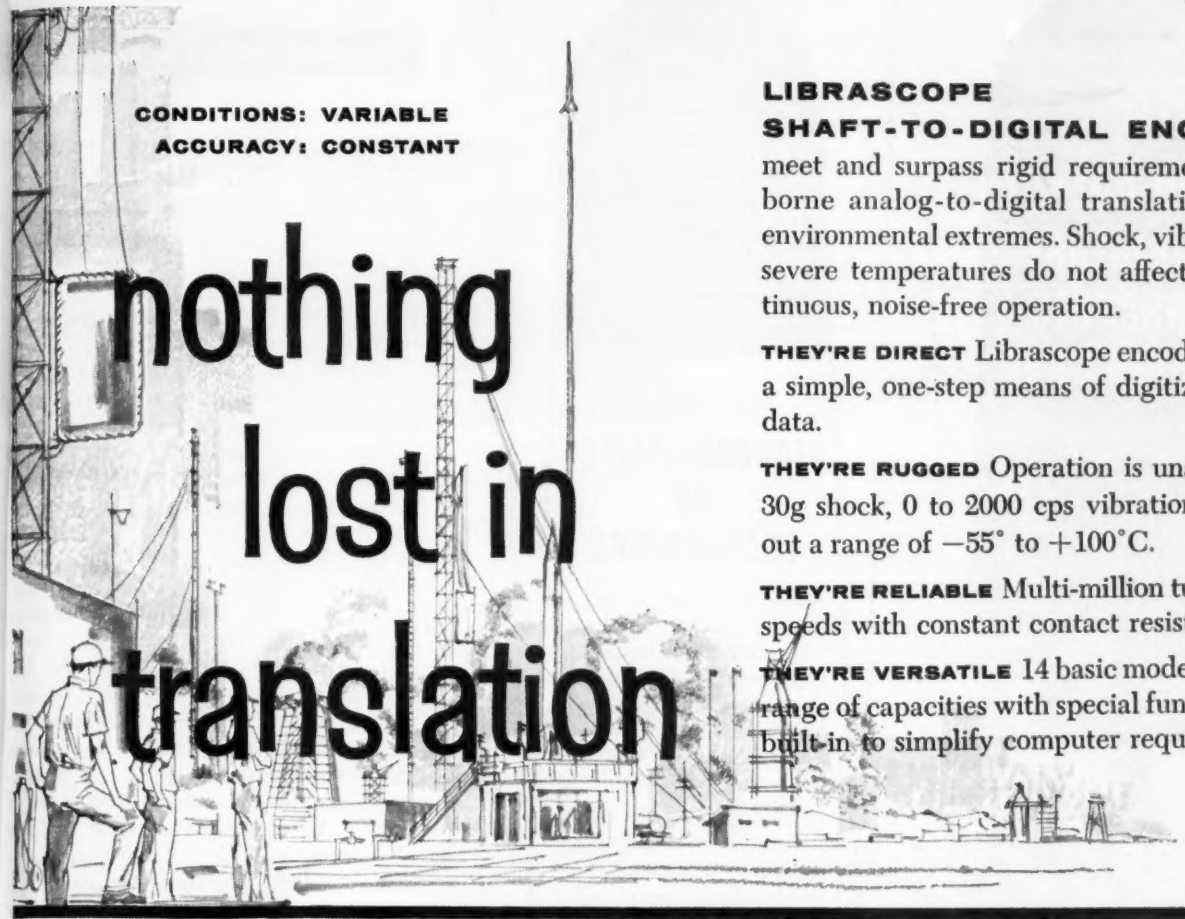
WORTH FILING

Screw Conveyor Drives

16-page bulletin describes compact screw conveyor drive complete with speed reducer, packing gland and drive shaft, all of which mount as a unit on a trough end. Drive is precision built with housings bored in line to receive Timken bearings for ample thrust and radial capacity. Triple seals prevent contamination. Units may be mounted in any position, on horizontal, inclined or vertical shafts, and require no sliding motor base for belt tensioning.

Source: Dodge Manufacturing Corp.
Mishawaka, Indiana

For your copy: Circle No. 132 on Inquiry Card



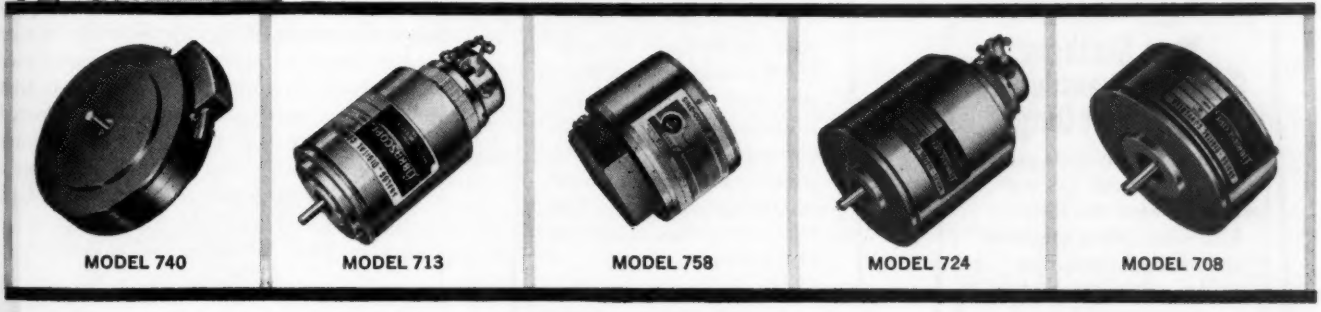
LIBRASCOPE
SHAFT-TO-DIGITAL ENCODERS
meet and surpass rigid requirements of airborne analog-to-digital translation despite environmental extremes. Shock, vibration, and severe temperatures do not affect their continuous, noise-free operation.

THEY'RE DIRECT Librascope encoders provide a simple, one-step means of digitizing analog data.

THEY'RE RUGGED Operation is unaffected by 30g shock, 0 to 2000 cps vibration, throughout a range of −55° to +100°C.

THEY'RE RELIABLE Multi-million turns at high speeds with constant contact resistance.

THEY'RE VERSATILE 14 basic models in a wide range of capacities with special function codes built-in to simplify computer requirements.



OUTPUT CODE	MODEL NO. @	TOTAL CAPACITY	RESOLUTION PER TURN	DIMENSIONS DIA. x LENGTH
PARALLEL BINARY (LINEAR)	740	10 bits (1024)	1024	4 3/16" x 2 1/4"
	743	13 bits (8192)	128	2" x 3 15/32"
SERIAL BINARY (LINEAR)	707	7 bits (128)	128	2" x 2 45/64"
	713	13 bits (8192)	128	2" x 3 15/32"
	717	17 bits (131,072)	128	2" x 4 13/16"
	719	19 bits (524,288)	128	2" x 4 13/16"
SERIAL BINARY (SIN-COS)	757†	7 bits per quadrant* (4 quadrants)	512	2 1/8" x 4 1/16"
	758†	8 bits per quadrant* (4 quadrants)	1024	4 1/8" x 3 3/16"
BINARY CODED DECIMAL (8-4-2-1)	723	2,000	200	3 1/16" x 4 23/32"
	724	20,000	200	3 1/16" x 4 23/32"
	733	3,600	200	3 1/16" x 4 23/32"
	734	36,000	200	3 1/16" x 6 3/4"
	735	360,000	200	3 1/16" x 6 3/4"
GRAY	708	8 bits (256)	256	3 1/16" x 1 13/16"

@All models available with internally mounted isolation diodes for sequential multiplexing applications.

†Available in hermetically sealed servo-driven package as Models 757-S and 758-S.

*Including limit 1 and polarity information. Sine and cosine functions generated simultaneously and independently. One turn of shaft generates 4 quadrants of information.

For full details on Librascope shaft-to-digital encoders write for catalog E 11-1.

L19-1

0001
0010
0011
0100
0101
0110

For information on career opportunities at Librascope, write Glen Seltzer, Employment Manager.

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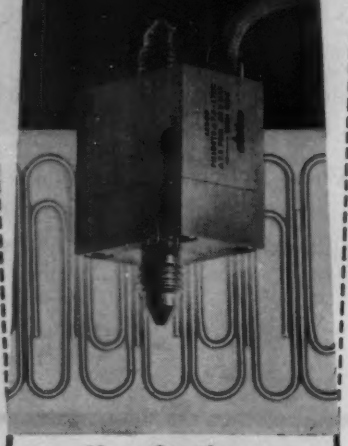
CIRCLE 19 ON INQUIRY CARD

STATHAM ANNOUNCES

HIGH OUTPUT MINIATURE UNBONDED STRAIN GAGE



New Statham Pressure Transducers With ¼ Volt Output

Statham's continuous product development has now provided the flight instrumentation engineer with subminiature transducers which are compatible with present day high level commutators. The ¼ volt output makes it possible to simplify instrumentation systems and at the same time provide the accuracy, reliability and service life characteristic of the unbonded strain gage. Write to Dept. EMD-602-1

STATHAM INSTRUMENTS, INC.
12401 West Olympic Boulevard
Los Angeles 64, California

Statham

CIRCLE 69 ON INQUIRY CARD

STATHAM INSTRUMENTS, INC., ANNOUNCES A DEVELOPMENT THAT IS SAVING THOUSANDS OF HOURS IN INSTRUMENT CHECKOUT AND DATA REDUCTION:

ELECTRICAL STANDARDIZATION OF TRANSDUCERS

After three years of operation on rocket test stands and months of extrapolation to the missile airborne instrument calibration problem, the method of *Statham Standardization* is ready for general use.

Briefly, it is an electrical technique whereby any number of Statham unbonded strain gage pressure transducers and accelerometers can be made to have: (a) the same transfer function, and (b) single shunt calibrating resistor standardization over a wide temperature range, with a fixed percentage of accuracy. The following benefits are obtained:

1 *Immediate access to meaningful data* after test.
2 *Elimination of calibration curves.*
3 *Fast, complete system electrical calibration.*
4 *Easy transducer system sensitivity checks.*
5 *Free interchangeability of transducers* from a pre-calibrated stock.

For full details write for Data File EMD-754-1.

STATHAM INSTRUMENTS, INC.
12401 West Olympic Boulevard
Los Angeles 64, California

Statham

CIRCLE 70 ON INQUIRY CARD

COMPONENTS DESIGN

DC Power Supply

A new DC power supply features transistor-driven magnetic amplifier regulators unusually fast response, precise regulation over a broad range of voltages centered about four popular industrial values in the 5 to 160-volt region for loads of up to 120 amperes. The unique combination of magnetic-amplifier regulation, with its high-current capability and immunity to short-circuit damage, and a transistorized driver amplifier, with its high-speed response, enables these supplies to furnish large amounts of DC power with the precise regulation normally found only in light-duty laboratory supplies. A static load change from zero to rated maximum, even for the 120-ampere units, causes the DC output voltage to deviate less than 1.0% or 50 millivolts (whichever is greater). The same degree of regulation is provided against line-voltage variations of ±10%. An unusual feature of the line is a set of modular auxiliary capacitor banks, which permits tailoring the transient response of the power supply to the needs of the application. A simple formula determines the capacitance required to hold the transient output voltage excursion to any selected value, and the appropriate capacitor bank assembly can be ordered from a group of twenty stock units. NJE Corp., Kenilworth, N. J.

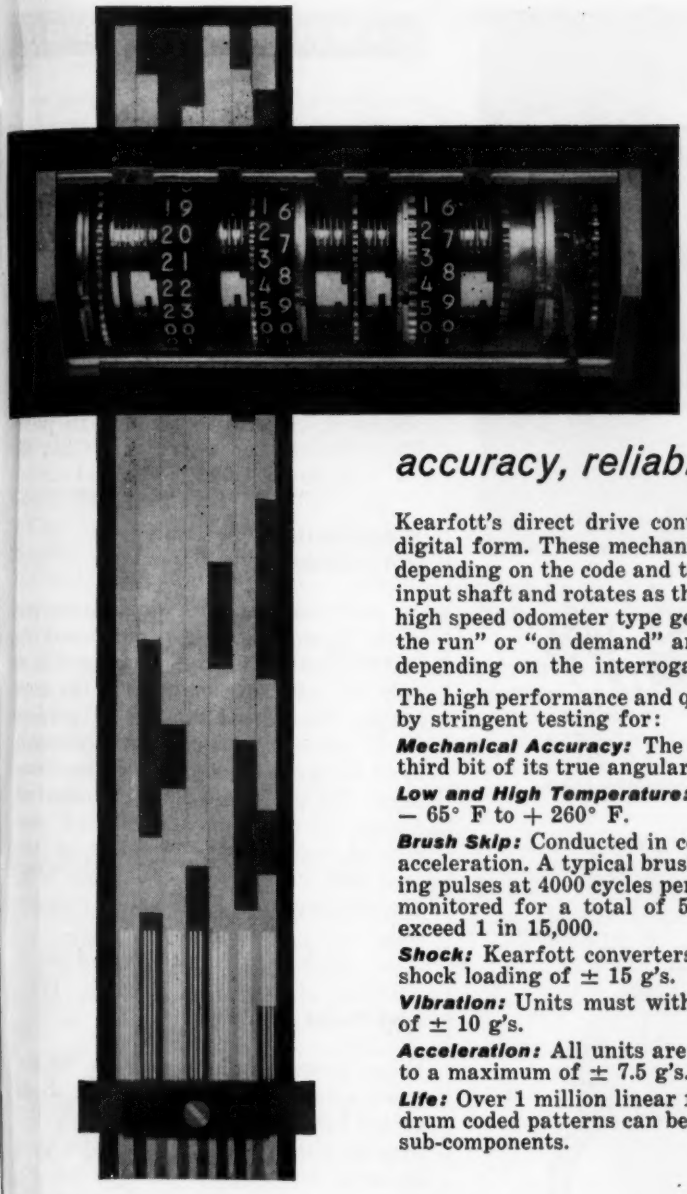
Circle No. 256 on Inquiry Card

Infinitely Variable Speed Drive With Planetary Reducer

A new planetary reducer makes it possible to offer a high torque, infinite range drive having speed ranges from 300 revolutions per minute to zero to 1 revolution per hour to zero with speeds accurately set to one part in four thousand. This new reducer develops a torque of 100 inch pounds. Built in overload protection prevents damage to the reducer, transmission or drive machinery. In-line design saves space and permits a "package" of motor, variable speed drive, control and reducer mounted with four bolts.

Transmission is also available with a variety of controls including remote micrometer, remote electrical, pneumatic and automatic controls of a variety of types. The transmission is available without motor or with built in motor of other specifications. Graham Transmissions, Inc., Menomonee Falls, Wisc.

Circle No. 246 on Inquiry Card



. . . Kearfott analog-to-digital converters

accuracy, reliability, varied capacities and codings

Kearfott's direct drive converters translate shaft rotation into electrical and visual digital form. These mechanically positioned units consist of coded drums, the number depending on the code and total count. The first, or units drum, connects directly to the input shaft and rotates as the shaft turns. On models where more than one drum is used, high speed odometer type gearing provides interconnection. All models can be read "on the run" or "on demand" and all tracks may produce simultaneous or serial readings, depending on the interrogating pulse.

The high performance and quality of Kearfott's analog-to-digital converters are assured by stringent testing for:

Mechanical Accuracy: The location of any code transition point must fall within one-third bit of its true angular position.

Low and High Temperature: All units operate efficiently at temperatures ranging from − 65° F to + 260° F.

Brush Skip: Conducted in conjunction with tests for temperature, vibration, shock and acceleration. A typical brush skip test employs 200 μsec., 23V DC amplitude interrogating pulses at 4000 cycles per second. With the shaft rotating, each output drum track is monitored for a total of 500,000 pulses, in which "lost" counts or "skips" will not exceed 1 in 15,000.

Shock: Kearfott converters are subjected to 18 shocks in three different planes with shock loading of ± 15 g's.

Vibration: Units must withstand vibrations between 5 and 500 cps with applied load of ± 10 g's.

Acceleration: All units are subjected to radial accelerations of varying magnitudes up to a maximum of ± 7.5 g's.

Life: Over 1 million linear feet (1000 hours at 82 RPM) of continuous brush travel on drum coded patterns can be achieved without excessive wear to drums, brushes or other sub-components.

Write for new ADAC brochure.

ANALOG-TO-DIGITAL CONVERTER CHARACTERISTICS

Kearfott Unit No.	423830-1	423607-1	Y1241-11A	P1240-11A	Y1240-11A	U1240-11	P1241-11A
Code (1)	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	C.B. (Gray)
No. of Drums	1	1	2	3	3	4	5
Range	0 to 84 in 348.5° of arc. 11.5° dead spot coded O	−19 to 0 to + 19	0 to 359	(+) 0 to (+) 999 (−) 999 to (−) 0	0 to 359.9	0 to 359.9	0-32,768 (2^{15})
Bits per Revolution	85	39	40	20	40	40	16
Revolutions for Total Range	1	1	9	100	90	90	2,048
Volts D.C.	23	12	23	23	23	23	10.5
Current (ma.)	20	20	20	20	20	20	20
Inertia (gm. cm.²) (2)	158	48	104	28	158	100	20
Unit Diameter (in.)	2⅛	1¾	1 15/16	1 1/16	1 15/16	1.875	1 1/16
Unit Length (in.)	31/32	1 1/16	1-43/64	1 15/16	2⅛	2.8125	3
Life (3)	10^6 revolutions or 10^3 hours						
Static Torque (in.-oz.) (4)	0.5	0.1	1.0	.5	1.0	1.0	2 (break) 1 (running)
Weight (oz.)	5	3.5	5.75	4	7.75	6.5	5
Maximum Speed (RPM)	1100	250	300	400	300	700	600
Dielectric (Volts DC)	500	500	500	500	500	500	500

(1) B.D. (Binary Decimal), C.B. (Cyclic Binary).
(2) Inertia measured at maximum trip.
(3) Under recommended conditions.
(4) At room temperature.

Engineers: *Kearfott offers challenging opportunities in advanced component and system development.*

Kearfott — A GENERAL PRECISION COMPANY

KEARFOTT COMPANY, INC., LITTLE FALLS, N. J.

A subsidiary of General Precision Equipment Corporation
Sales and Engineering Offices: 1500 Main Ave., Clifton, N. J.
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CIRCLE 21 ON INQUIRY CARD

new

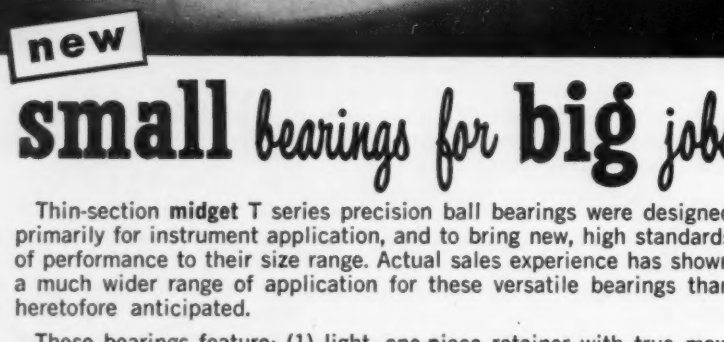
small bearings for big jobs

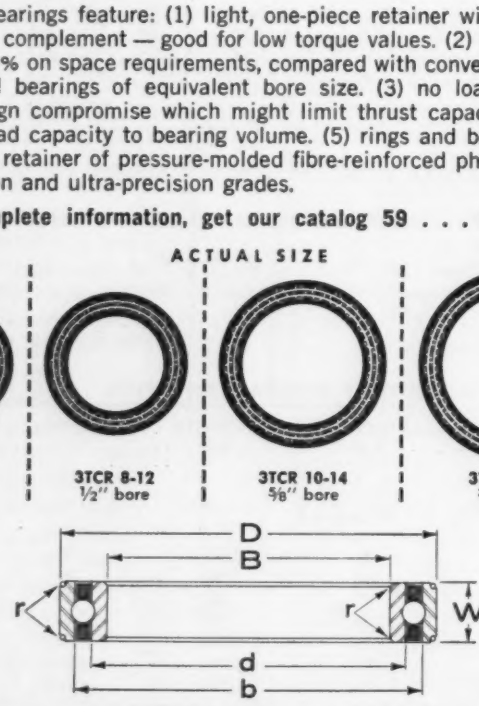
Thin-section **midget** T series precision ball bearings were designed primarily for instrument application, and to bring new, high standards of performance to their size range. Actual sales experience has shown a much wider range of application for these versatile bearings than heretofore anticipated.

These bearings feature: (1) light, one-piece retainer with true maximum ball complement — good for low torque values. (2) savings from 46% to 90% on space requirements, compared with conventional inch-series ball bearings of equivalent bore size. (3) no loading slot or other design compromise which might limit thrust capacity. (4) high ratio of load capacity to bearing volume. (5) rings and balls of stainless steel; retainer of pressure-molded fibre-reinforced phenolic. Made in precision and ultra-precision grades.

For complete information, get our catalog 59 . . . Write today.

ACTUAL SIZE





*B bore ± .0002	*D o.d. + .0000 − .0004	W width + .0000 − .0050	†r radius	b outer land ± .001	d inner land ± .001	Balls no.	Balls size	‡L lbs.	§S lbs.
.3750	.6250	.15625	.010	.542	.457	16	1/16	77	110
.5000	.7500	.15625	.010	.672	.587	21	1/16	89	144
.6250	.8750	.15625	.010	.797	.712	24	1/16	94	165
.7500	1.0000	.15625	.010	.922	.8375	30	1/16	101	206

Dimensions are in inches. *Tolerances shown are for Precision Grade. Write for Ultra Precision Grade tolerances. †r is maximum fillet radius on shaft or housing that bearing will clear. ‡Radial load capacity at 500 rpm and 2500 hours average life. §Static non-Brinell load capacity.

split ballbearing
A DIVISION OF MPB, INC.
514 HIGHWAY FOUR, LEBANON, NEW HAMPSHIRE
CIRCLE 22 ON INQUIRY CARD

Variable Capacitors

Variable capacitor with a maximum capacitance of as much as 4.4 microfarads, has close tolerance adjustment over the whole capacitance range, one continuous adjustability, as well as accurate repeatability; ideal for many applications, including wide range R-C or L-C circuits; adjustable capacity standards; integrating circuits; ferro resonance circuits; low and high pass-filters. Plastic Capacitors, Inc., Chi., Ill.

Circle No. 130 on Inquiry Card

Subminiature Precision Potentiometer

A new subminiature single-turn pot offers linearity to 0.3 percent and 2,500,000 cycle life in a package that is only ½" in diameter and ⅜" in case length. This is said to be 25 percent to 40 percent smaller than previously available pots of comparable performance. The use of a cylindrical mandrel, instead of the conventional card, permits a significant shortening of the case and more precise winding techniques. Daystrom Pacific, Los Angeles, Cal.

Circle No. 129 on Inquiry Card

Low Noise Diodes

Noise temperatures as low as 50 degrees above absolute zero for a diode cooled by liquid nitrogen and only 100 degrees above absolute zero operating at room temperature have been obtained in a high gain 3000 megacycle parametric amplifier using sample diodes of a newly developed type. The diode is the heart of the parametric amplifier but also has other important microwave applications such as switching and harmonic generation. It is available in two rugged and hermetically-sealed versions—one for the region below 1000 megacycles and a second for the microwave region.

Dr. R. A. Gudmundsen, representing the Hughes Semiconductor Division, has announced that because of newly developed modular line production techniques, these diodes are available at a price in the same range as good microwave mixer crystals. He pointed out that the exceptionally low noise performance of amplifiers using the new diode is already in a range competitive in many applications with the solid state maser, which holds the record for absolute minimum noise performance. However, the parametric amplifier does not require low temperatures for operations. The parametric

amplifier does, however, have two channels of amplification, usually called the signal and idler channels, which were used simultaneously to obtain the low noise temperatures quoted above. As a further comparison, the best reported low noise microwave tubes have noise temperatures of about 300 degrees K at 3000 megacycles, but have the advantage of single channel amplification and electrical tunability.

The 3000 megacycle amplifier gives 30 db of amplification with two megacycles bandwidth of 10 db of amplification with 25 megacycles bandwidth. Such amplifiers would, of course, be useful for microwave and UHF receivers where greater sensitivity or lower receiver noise is required.

The production models of the Hughes diode, designated HPA-2800 and HPA-2810 have a nominal cutoff frequency of 70,000 megacycles at maximum back bias with a nominal zero-bias capacitance of 2.5 μμf. Its exceptional noise performance is attributed to its low equivalent series resistance at microwave frequencies.

Circle 85 on Inquiry Card

Power Transformer

Development of voltage doubler circuits using silicon rectifier power supplies is now possible with a new Triad R-93A power transformer. It provides taps on both primary and secondary windings to allow several variations of output voltage, and is electrostatically shielded. Rated at 110/120 volts, 60 cps primary and 150/160/170 volts @ 500 ma secondary, the R-93A also supplies filament power of 6.3 v-6A center tapped for hum reduction. In a voltage doubler circuit, the maximum D.C. available for preamps and amplifiers is 250 ma with approximately 480 volts. Triad Transformer Corp., Venice, Cal.

Circle No. 226 on Inquiry Card

Capacity Sensitive Control

Utilizing standard laboratory equipment, this ultra-sensitive control for laboratory processes operates on the principle of detection of minute capacity changes as encountered in the rise or fall of manometers, thermometers, barometers, floats, in flowmeters or precise mechanical movements. Operation is simple and installation generally consists of only one clip snapped around the indicating device. Physical contact in the form of probes, etc. is eliminated. Any mechanical movement can be controlled by the device. H. S. Martin & Son, Evanston, Illinois.

Circle No. 170 on Inquiry Card

SLOW MOTION IS OUR BUSINESS

NEW!

Brevel "F" motors have **fully-enclosed gear trains;** provide maximum protection of gears against dirt.

Designed to give maximum power transmission at lowest noise level by use of specially cut helical gears. Optional features — brake, clutch, and cooling fan — make it suitable for a wide variety of applications. Like all Brevel Motors, this new "F" Motor provides reliable power at low cost.

Write, wire, or phone today for Catalog 27R.

You will receive information on Brevel's complete line of small gear head motors.

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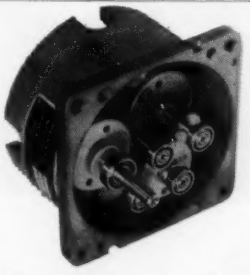
CIRCLE 23 ON INQUIRY CARD



Off-the-Shelf Gear Reducer

RATIOS FROM 5:1 TO 3125:1

Link's Hi-Precision 012 Gear Boxes offer the flexibility, performance range and construction qualities you'd expect to find only in costly custom systems. Designed for application with servo mechanisms, control equipment, instruments, computers and motor drives, Link 012 Gear Boxes are light (16 oz.) and compact (3½" x 3½" x 2-7/32"). They feature anodized aluminum AGMA Precision Class 3 gears. Class 1 precision ball bearings and lifetime lubrication.

Other Model 012 Features:

- Output rated at 120 oz. – in. at slow shaft
- Friction torque of .004 oz. – in.
- Backlash less than .27°
- Avg. total inertia (reducer & coupling) 4.5 gm cm²
- Efficiency 97% at 120% rated load; 95% efficient at 10% rated load
- Available in ratios from 5:1 to 3125:1

Dual output models also available for many ratios . . . Link adapter kits integrate 012 Gear Box with commonly used servo motors.

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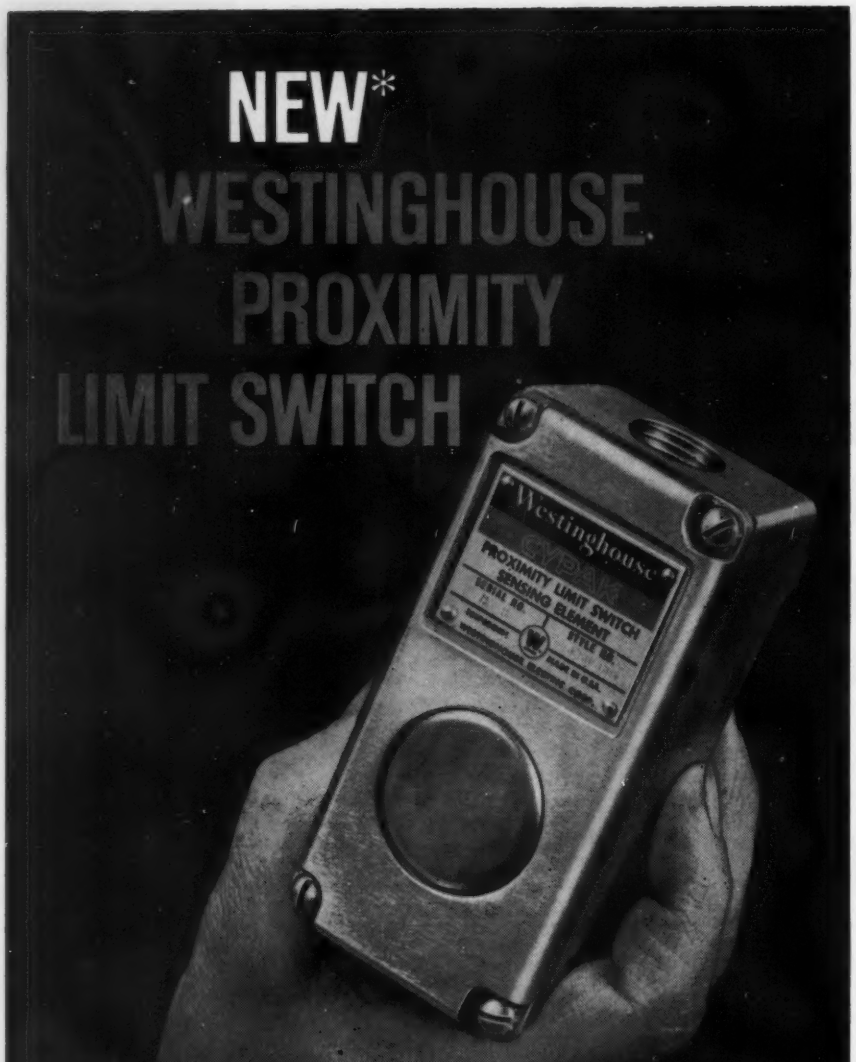
CIRCLE 24 ON INQUIRY CARD



...WON'T WEAR OUT... NEVER NEEDS REPLACEMENT

No tubes . . . no moving parts to weaken and fail from wear . . . not affected by dust, dirt, oil mist or iron filings . . . will even operate under water . . . sensing heads available for distances of ½ inch and 2 inches . . . also for explosion-proof applications . . . corrosion and vibration resistant . . . won't spark, pit or wear, because there are no contacts.

Sure, they cost a little more initially. But we haven't seen the application yet where the new Westinghouse proximity limit switch can't pay for itself time and again through eliminated replacements and machine down time.

GET ALL THE FACTS about new Westirghouse proximity limit switches . . . see how and where they can benefit you. Write to Westinghouse Electric Corporation, Director Systems Department, 356 Collins Avenue, Pittsburgh 6, Pennsylvania. J-01011

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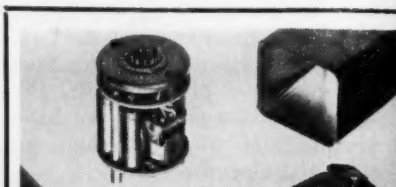


Packaged Controls

A new line of miniaturized "package" controls will do the work of much larger units in all but the most sophisticated applications. Except for certain limitations inherent in smaller space, the new controls are available from Assembly Products, Inc. with most of the standard circuits usually built around API meter-relays. Power supplies and other components are self-contained. Either a-c or d-c meter-relays may be specified. Both types measure signals from almost any variable and trigger appropriate control action at adjustable set points. With simple limit circuits, meter-relays of any sensitivity may be specified, beginning with 0 to 5 micrometers or 0 to 5 millivolts. For automatic circuits, sensitivity of meter-relays begins at 200 micro-amperes. Chief limitation of the new controls is a maximum rating of load relays in some models at 2 amperes. There is also insufficient space for all the components needed by the most complicated meter-relay circuits.

Circle No. 134 on Inquiry Card

WORTH FILING

Hi Strength Latch Brochure

30-page brochure on general purpose and high strength latches is unique in that it is actually a drawing aid, laid out so that housings may be traced from one set of pages and suitable fittings may be traced from a matching set of pages. Each latch has two basic components: a housing assembly and a fitting assembly. Designs cover mechanical, electronic, electrical or hydraulic applications for radomes, engine cowlings, camera doors, access doors, radar consoles, securing heavy equipment, missile sections, missile compartment and missile access panels and doors.

Source: Simmonds Aerocessories, Inc.
Tarrytown, New York

For your copy: Circle No. 227 on Inquiry Card

Upping Temperature Limit of Rotary Components

Kearfott Company, Inc. employs a novel method for solving the problem of operating rotary components such as servo motors and synchros at temperatures higher than their rated upper temperature limits. By means of a simple but effective finned aluminum heat dissipating coil that is easily clamped around the component's housing, internal heat generated by continuous operation is rapidly conducted to the coil's fins where it is readily radiated to circulating cooling air, whether introduced by a blower or where the normal ambient may be cool enough without a blower. Consisting only of a deeply threaded short tube having an inside diameter slightly less than that of the component's outside housing diameter, this heat dissipating coil is slotted lengthwise to permit insertion of a spreader bar which springs the coil just wide enougth to insert the particular unit requiring better heat radiation. When the component is positioned properly within the coil, the spreader bar is removed, allowing the coil's inherent spring tension to clamp the unit firmly and in intimate contact with the smooth internal surface of the coil, thus providing a heat conducting element that "soaks up" generated heat and conducts it to the fin edges for rapid dissipation. Kearfott Co., Inc., Clifton, New Jersey.

Circle No. 126 on Inquiry Card

WORTH FILING

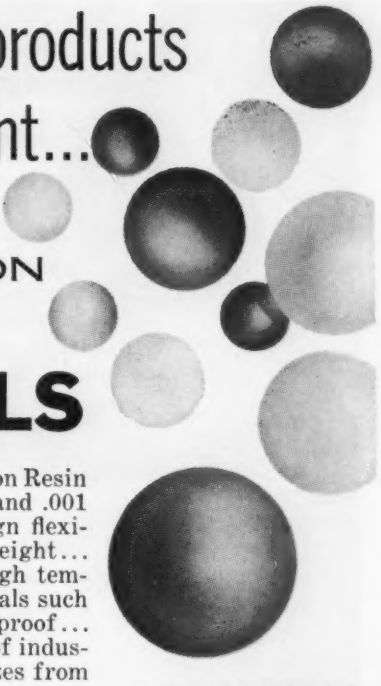
Design Handbook

Thirty-six page design handbook features a complete line of Pressure Switches. Each page describes a specific type of switch (diaphragm, bourdon tube, or piston) and contains detailed information on electrical and operating characteristics, a comprehensive ordering chart, adjustment instructions, spare parts table, parts blow-up of the model, and a dimension diagram. The catalog also serves as a manual of technical information including a glossary of terms, an easy-to-use pressure switch selection chart, electrical rating tables, functional schematic symbols, general operating, engineering and service data and a helpful trouble shooting and maintenance checklist.

Source: Barksdale Valves
Los Angeles, Cal.
For your copy: Circle No. 164 on Inquiry Card

new way to make products better, more efficient...

ACE PRECISION NYLON BALLS



Precision manufactured from DuPont Nylon Resin to close tolerance of ±.001 on diameters and .001 on sphericity, Ace Nylon Balls give design flexibility and production economy. Light in weight... tough at low temperatures... stable at high temperatures... resistant to corroding chemicals such as sulphuric acid, etc.... almost abrasionproof... these mass-produced balls have hundreds of industrial applications. Come in 14 standard sizes from ⅛" to ¾".

Complete facilities for fabrication of plastic parts for all industries. Estimates submitted promptly on receipt of blueprints or specifications.

Write for Bulletin N, samples, price list, TODAY.

EXTRUSION MOLDERS AND FABRICATORS

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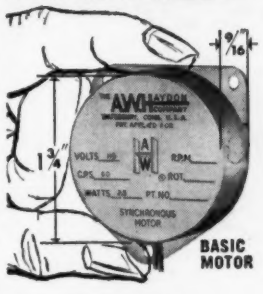
ANOTHER FIRST...



THE ONLY *Electro-Reliable* A.C. TIMING MOTOR

Thinner... Quieter...
More Reliable... More Versatile

FINGER-THIN...
Only 9/16 Inches Short... Only 1¾ Inches in Diameter... very compact... reduces the size of your equipment.

WHISPER-QUIET...
Strictly an electrical motor... practically noiseless... no rattling of gears or ratchets.

HIGH TORQUE...
¼ oz. inch at the rotor with an instantaneous start and stop... requires only 2½ watts... can replace larger motors in recorders, controls and telemetering equipment.

HIGHEST RELIABILITY...
Longer life... no one-way gears or ratchets to fail... provides millions of operations without any trouble.

Send for Special Illustrated Bulletin AWH MO-806

SPECIFICATIONS

Standard Voltage Ratings: 6, 12, 24, 115, 230 Volts
Frequency: 60 CPS Standard, 25, 50 CPS Available
Power Input: 2.5 Watts Maximum (60 CPS)

BASIC MOTOR
Weight: 4 ounces
Speed: 300 RPM
Torque: ¼ oz-in.
Length: 9/16 inch

WITH INTEGRAL GEAR TRAIN
Weight: 5 ounces
Speed: 300 RPM to 1/6 RPH
Torque: 30 oz.-in. @ 1 RPM
Length: ⅞ inch

WITH INTEGRAL GEAR TRAIN

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WATERBURY 20, CONNECTICUT
Custom Design & Manufacture Of Electronic And Electro-Mechanical Timing Devices

CIRCLE 27 ON INQUIRY CARD

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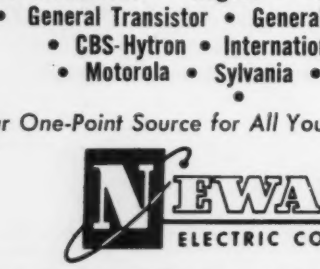
CIRCLE 28 ON INQUIRY CARD

10 x p = J • R • L



This enigmatic equation was invented to emphasize that JRL instruments permit measurements ten times as precise as those possible with other currently-available "precision" equipment. Model RVD-105 Relay-Operated Voltage Divider, for example, permits automatic or manual conversion of digital data to analog equivalents with an accuracy of ten parts per million. (1, 2, 2, 4 binary-decimal code is standard, but any desired code can be furnished). The built-in high-speed relays can also be programmed for rapid synthesis of resistance values, ratios, voltages, or currents, with the same high resolution and accuracy. Price, $1280. Write for bulletin L-59-3.

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CIRCLE 29 ON INQUIRY CARD

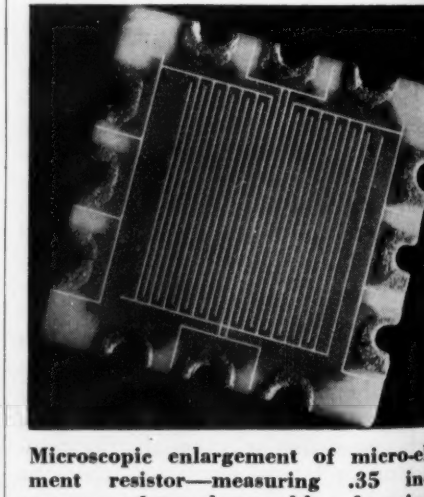
MOLECULAR STRUCTURED RESISTORS

40,000 To The Pound

Market plans for new molecular-structured resistors, ten times smaller and lighter than present resistance components, were anonunced by Daystrom-Weston Divisions, Daystrom, Inc. The new micro-miniature resistors are the first commercial production of elements developed from the micro-module concept—the idea of combining extremely small elements of uniform shape and size into a single tiny module capable of performing complete circuit functions.

Basically, the micro-miniature resistors are a solid state material in the form of a ceramic wafer approximately 10 thousandths of an inch thick and .35-inch square. Suitable substrates of these micro-wafers are inscribed with a series of "isolation lines" that produce the resistor characteristics desired. Single or double sided resistor elements can be designed, and various combinations of circuitry can be employed with the basic micro-element. These wafer-like elements may then be combined into modules of standard size and shape comprising circuit sub-assemblies.

"The ten-to-one size and weight reduction obtained with these micro-resistors," Allison said, "opens new possibilities for design flexibility and economy in electronic equipment and systems, such as computers, satellites,



Microscopic enlargement of micro-element resistor—measuring .35 inch square and ten thousandths of an inch thick—shows how resistance characteristics are inscribed in the substrates. This micro-element contains two resistors, but also may be inscribed on the reverse side to make four resistors.

missile guidance systems, and communications networks." Each resistor element—weighing 50 milligrams—contains four resistors, averaging 10,000 elements (or 40,000 resistors) to the pound and a packing density of 600,000 parts per cubic foot. Highly reliable and stable, the microscopic resistors are developed in wafer element forms designed for reliabilities of meantime to failure of 100,000 hours. They can be designed for required values of 10 ohms to one megohm. Multi-layer structures of the micro-element forms can extend this range.

Basic module forms may be stacked or interconnected, using as many or few micro-elements as desired. When assembled, a 1/100-inch space is allowed between micro-elements to provide electrical de-coupling as well as allowance for joints and tolerances. After assembly of the elements and completion of all internal connections, the module is sealed by molding or encapsulation to form a solid body. The small, modular solid formed—usually smaller than a cube of sugar—is a complete aggregate ready to function as an amplifier, oscillator, filter or some other type of electronic sub-assembly.

Circle No. 116 on Inquiry Card

Electric Motor For Flyaway Hoist

A new, compact AC motor for flyaway cargo hoist application meets MIL-M-7969B, is reversible and features a quick stopping magnetic brake and torque limiting clutch. Nominal force delivered at the drive shaft is 5 inch-pounds at 7200 rpm. Starting torque is better than 10 inch-pounds. The duty cycle is 3 minutes "on" and 10 minutes "off." Designed for 200-volt, three-phase, 400-cycle systems, the motor is 4″ in diameter and weighs 7.5 pounds. An MS 3102A-18-4p aircraft connector is provided. Western Design, Div. of U. S. Industries, Inc., Santa Barbara, Cal.

Circle No. 253 on Inquiry Card

WORTH FILING

Motoreducer Bulletin

28-page bulletin describes complete line of all-steel, helical gear, all-motor and integral motoreducers. Revisions include changes in selections, dimensions and weights to incorporate rerated NEMA standard motors from 1 through 75 hp; increased overhung load and thrust capacities for the first three sizes.

Source: The Falk Corp.
Milwaukee 1, Wisc.
For your copy: Circle No. 231 on Inquiry Card

ANNOUNCING

A NEW TENSILE TESTER FOR WIRE TERMINALS

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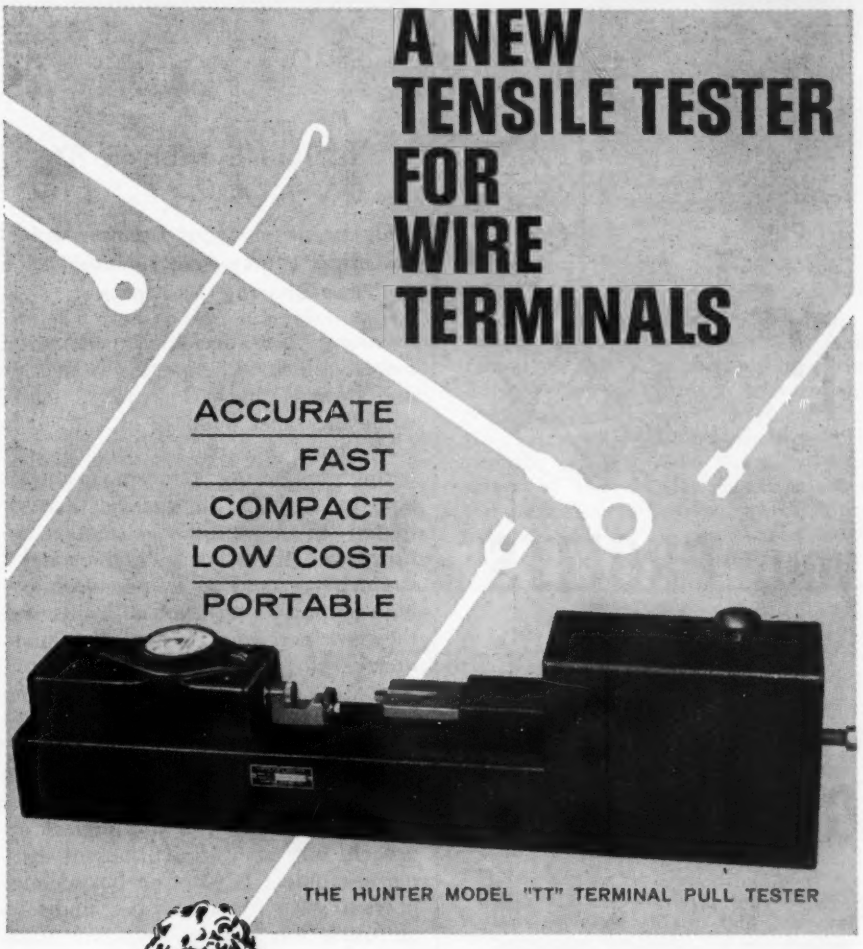

THE HUNTER MODEL "TT" TERMINAL PULL TESTER

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To expedite receipt of detailed literature on the Model "TT", write direct to Quality Control Department.

The "TT" Tester—latest addition to Hunter's growing line of quality control equipment—brings laboratory accuracy to production-line testing (±0.5% of full-scale reading). Though you'll find it adaptable to many other tensile tests in ranges up to 0-500 pounds, its special job is checking the secureness of solderless terminals crimped on wire. Automatically opening and closing jaws grip the wire sample; a turret-type gage head indexes quickly to hold any size terminal; load is applied at a preset rate by an adjustable air cylinder; and breaking load registers and is held on a direct-reading dial until reset by a touch of the quick-reset tab. Over-all speed of testing is up to ten times faster than by conventional methods.

Whether you attach terminals in your plant, or are supplied with wire assemblies—whether you use it in the plant or the laboratory—the "TT" Tester will help you establish useful standards and control quality by sample testing.

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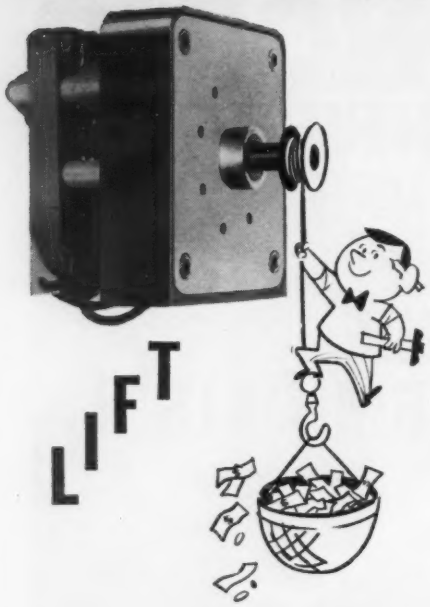

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CIRCLE 31 ON INQUIRY CARD

SYSTEMS DESIGN

HIGH-VOLUME TELEMETRY

Galvanometer Light Beams And Photo-Multiplier Tube Replace Rotating Wiper-Arm Assemblies and Chopper-Stabilized Amplifiers In Time-Sharing Multiplexer

In recent years, accuracy and environmental tolerance demanded from sensing devices have increased tenfold while the sheer *quantity* of data to be telemetered has reached almost staggering proportions. Transducers available today with the specifications required to meet these demands are "low-level" transducers—thermocouples, strain gages, and strain-gage pickups—with outputs in terms of millivolts. Yet, they are not used because the inadequacy of available equipment has forced the conclusion that commutation of millivolt-level signals is impractical.

High-volume telemetry dictates that many transducer outputs must "time share" one telemetered frequency. PDM commutation is a practical approach, but again, limitations of existing equipment have often forced engineers to settle for second best and forego using the desired low-level transducers—because the three approaches generally in use today have severe limitations.

The familiar potentiometer-type transducer is still widely used to provide a voltage-output signal capable of directly modulating the telemetering oscillator. Output from this type of transducer can be successfully commutated with mechanical commutators or electronic switches. However, the high-level output required restricts the characteristics of the potentiometer-type transducer and prevents it from keeping pace with many current measurement requirements.

For extreme environmental conditions beyond the range of potentiometer-type pickups, "low-level" transducers have been used with their output *amplified prior to commutation*. Complex signal-conditioning equipment used for this amplification has interjected both error and unreliability into the system. To overcome many of these problems, engineers have turned toward *commutation prior to amplification*. This method immediately reduces size, weight, and power consumption. But, the low commutation rate and the high maintenance cost prevent wide spread use of mechanical commutators.

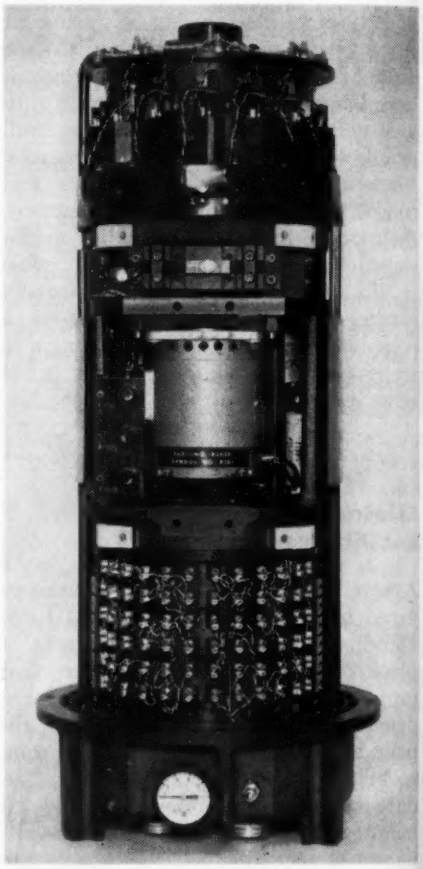


Fig. 1. Shock-mounted Plexicoder operates in any position; repair, maintenance, and adjustment in the field is a design feature. Its high sensitivity permits it to operate directly from the output of thermocouples, strain gages, and strain-gage-bridge transducers. The input signal of 6 millivolts produces full scale pulse duration. It also accepts negative voltages.

DESIGN PARAMETERS

Disadvantages associated with low-level PDM are basically only the limitations of the commutation equipment itself. A short study of the design parameters for the ideal equipment indicate the following desirable characteristics:

Life—Requirements of reliability and economy dictate that equipment should have a service-free life of at least 1000 hours of operation.

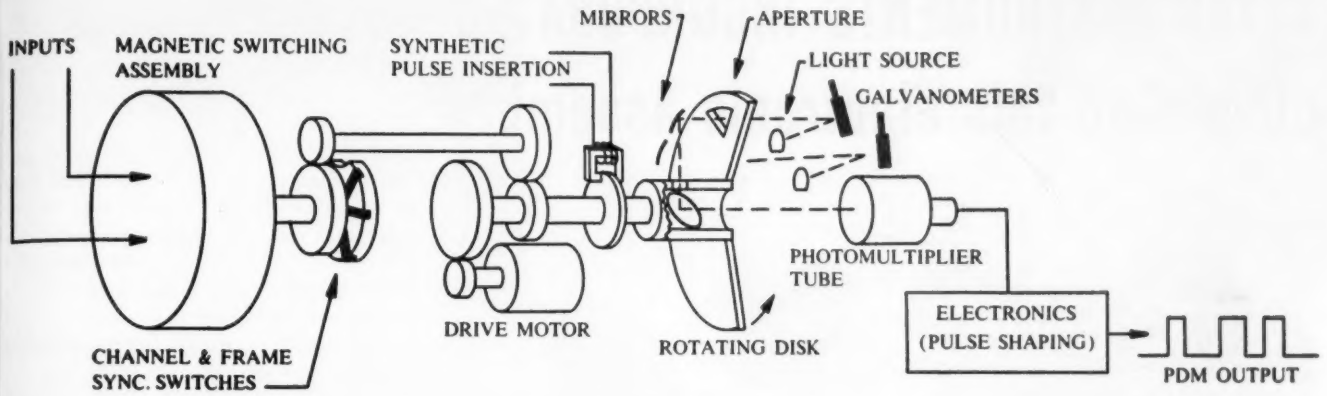


Fig. 2. Each input signal feeds through two hermetically sealed, magnetically operated switches (DPST) to a galvanometer. Unique design of this input switch eliminates induced voltage. Moving magnets open and close each switch in a predetermined time sequence so that a given galvanometer is energized by a transducer for only a specific time, starting sometime before sampling by the coding aperture. The input switch enables 15 galvanometers to sample 90 inputs, with each galvanometer sampling six input channels in time sequence. Light beams from all 15 galvanometers are directed at a rotating disk that contains an aperture cut in the shape of a right triangle. As the triangular opening moves past a given galvanometer and acoss its light path, light is admitted briefly to the surface of a photomultiplier tube. As long as the beam strikes the tube, a voltage pulse is developed and maintained in the tube output. The time duration of the pulse is directly proportional to the beam's position along the hypotenuse of the aperture. The position of the light beam is determined by the angular displacement of the galvanometer mirror, which is proportional to the current input to the galvanometer coil from the transducer.

Input Characteristics – Equipment should have a low impedance input, not referenced to ground, and should accept positive or negative, balanced or unbalanced signals. It should accept the outputs of thermocouples, strain gages, and strain-gage-bridge transducers with voltage levels of less than 10 millivolts and produce *full-scale* pulse duration in the output.

Bandpass–Bandpass characteristics of the system should be restricted to accept only the static and quasi-static data for which the system is intended. The bandpass characteristics should be designed to reject high-frequency noise and spurious signals superimposed on the transducer signal, thus permitting the PDM signal to yield true average data.

Output Characteristics – PDM output should be in accordance with IRIG standards and practice, and of the proper voltage and impedance to directly modulate telemetering transmitters and tape recorders presently in use.

Environment – Equipment should be capable of operation from sea level to extreme altitudes, and over a wide range of temperatures, accelerations, and vibrations.

Physical Parameters – Design should feature minimum size, weight, and power requirements.

Serviceability – Design should permit servicing and routine adjustment in the field.

Consolidated Electrodynamics' engigineers satisfy these requirements with their type 40-101 Plexicoder which commutates low-level signals from up to 90 transducers at 90, 112.5, 225, or 900 samples per second and converts them into duration-modulated pulses suitable for telemetering or magnetic-

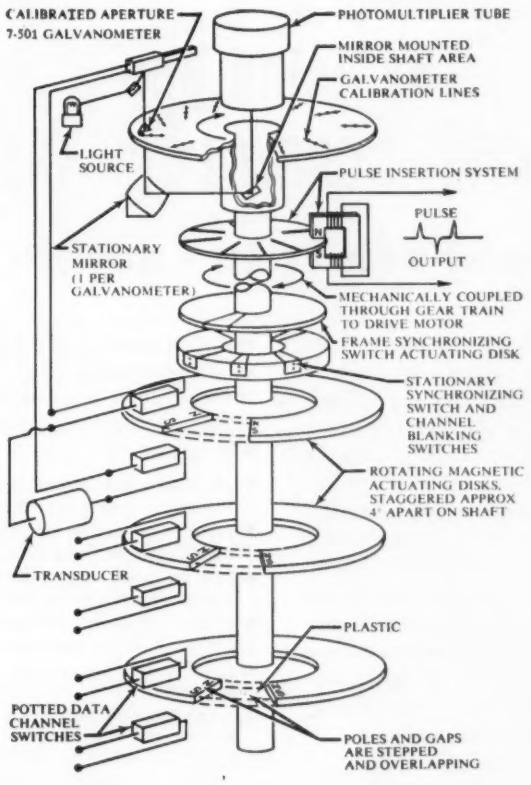
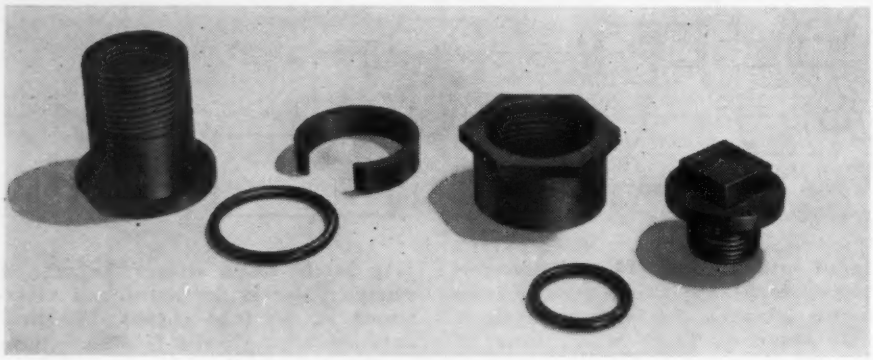


Fig. 3 Plexicoder's arrangement of switches, optics, and electronics enables 90 separate transducer inputs to be switched to individual galvanometers in a programmed sequence. Basic switch element is the Revere Glasswitch Relay. In normal operation, a magnetic field pulls the switch contacts together. Removal of the magnetic field causes the spring constant of the movable switch leaf to pull the switch open again. These switch elements are hermetically sealed and have a life expectancy in excess of 200,000,000 cycles of operation. A permanent magnet adjacent to each Revere switch element holds it firmly closed against its spring constant. The light weight rotor which operates the switches carries a magnet structure strong enough to oppose the stationary magnets and hold the switches open.

TEXAS INSTRUMENTS INCORPORATED simplified this electronic assembly



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CIRCLE 32 ON INQUIRY CARD

tape recording. The Plexicoder uses light beams and a photomultiplier tube in place of rotating wiper-arm assemblies and chopper-stabilized amplifiers. The design is based on magnetic switching and eliminates transients in the data-channel input circuit by using galvanometers with their inherent, natural filtering characteristic.

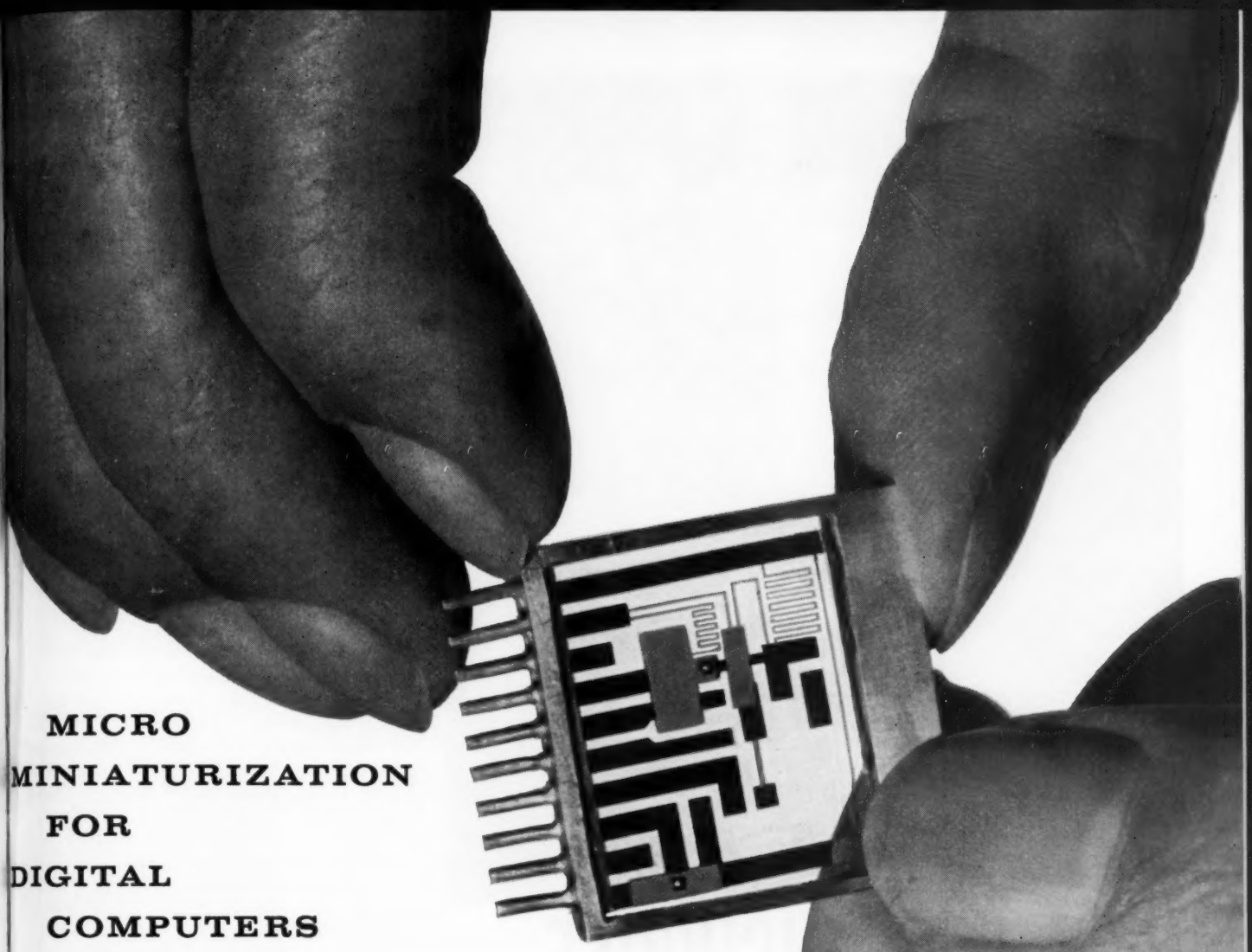
PRINCIPLE OF OPERATION

Figure 1 details the Plexicoder's principle of operation. In this deisgn, the original transducer signal is converted into an angular deflection of a galvanometer movement and is then converted into the angular sweep of a light beam, into bursts of light, and into voltage pulses. Duration of each pulse is a direct linear function of the original transducer input signal.

Each output pulse of the photomultiplier tube is reshaped electronically to provide a nearly perfect square wave in the output for either magnetic tape recording or other purposes. The data-channel period, or time interval between leading edges of successive pulses within any one frame, is uniform from interval to interval. The nominal data-channel period is equal to one divided by the total commutation or sampling rate. A synchronization switch, which effectively blanks out data-channels (usually the last two channels) delivers a framing synchronization pulse.

GALVANOMETER DESIGN

Consolidated Electrodynamics' Plexicoder accepts signals in an almost infinite variety of ranges through its specially designed galvanometers. Their flat frequency response, from 0 to 88 cps, provides inherent filtering of each data channel. Operating normally in a temperature-controlled magnet block at +150F, the galvanometers withstand a temperature +250F without damage. Instead of utilizing mirrors the galvanometer has a reflecting jewel 0.010" in diameter; this substitution was possible since the amount of reflected light, as opposed to recording on photographic paper, is not important; only the presence or absence of light at the surface of the photo-electric multiplier tube is significant. Design also virtually eliminated problems of static and dynamic balance by reducing the size and weight of the mirror normally carried on the galvanometer suspension, thereby reducing the inertia of the sys-



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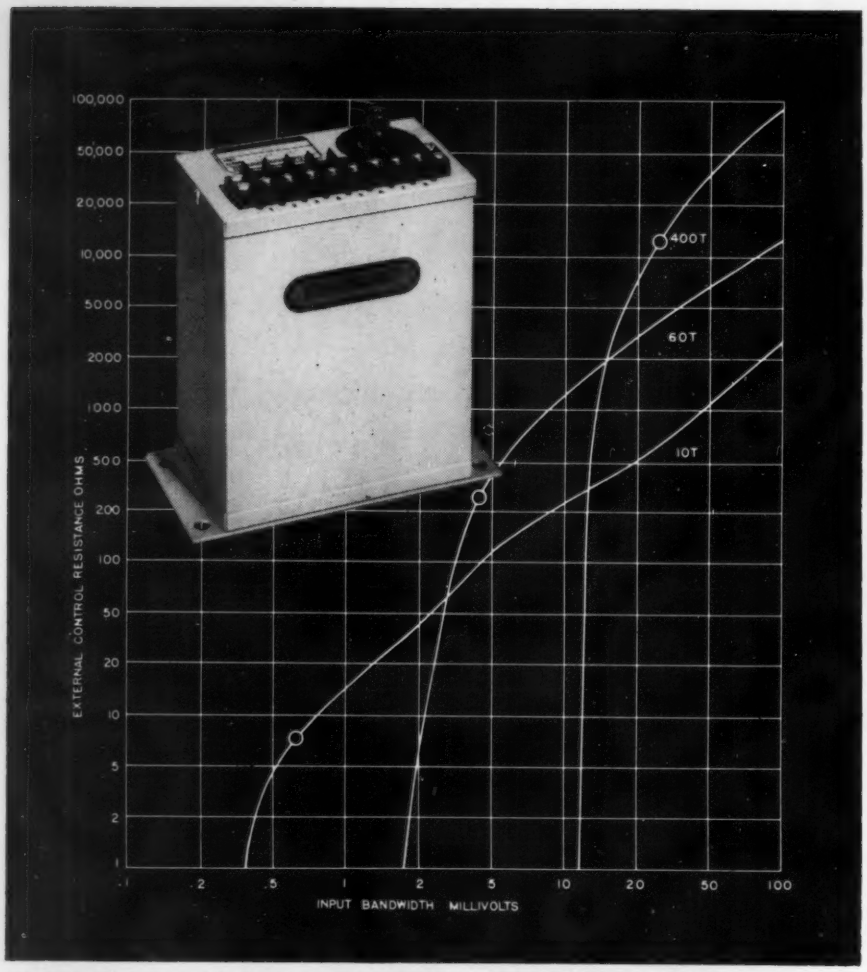

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tem to a practical minimum, and permitting proportional gains in sensitivity at a given bandwidth. Because the natural galvanometer frequency is 142 cps with a flat frequency range to 88 cps, it rejects high-frequency noise. For example, a large step-function impressed on the input circuit during the sampling period produces only negligible error, because the galvanometer's limited frequency response will not permit it to follow. From this analysis, the galvanometer functions as a clamp; static or quasi-static variable is faithfully reproduced and noise effectively rejected.

ELECTRONIC DESIGN

Electronics in the Plexicoder was minimized to assure reliability. In addition to the photo tube, there are only two dual triodes and two voltage regulators. Triodes provide amplifier, cathode follower, and multivibrator functions. The photo tube provides a duration modulated voltage pulse in its output.

Coming out of the photo tube, the voltage pulse is reshaped electronically and then differentiated. The resultant spikes are used to trigger a bistable multi-vibrator circuit which provides the PDM output pulses. Actually, there is a choice of two outputs: one is a five-volt output which can be used to drive a subcarrier oscillator, transmitter, or other device; the other is a one-volt output which can be used to feed a magnetic-tape recorder.

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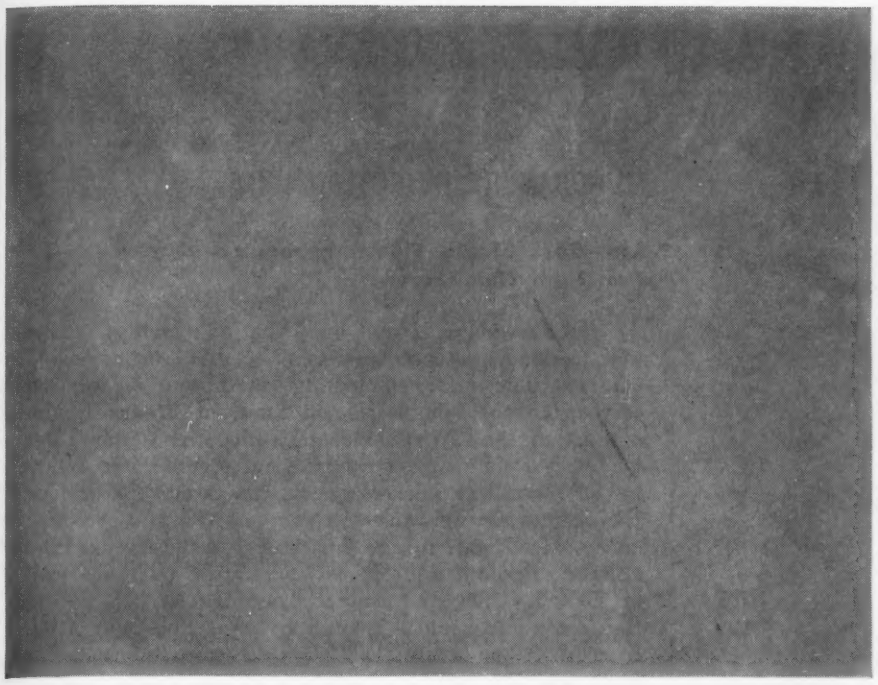

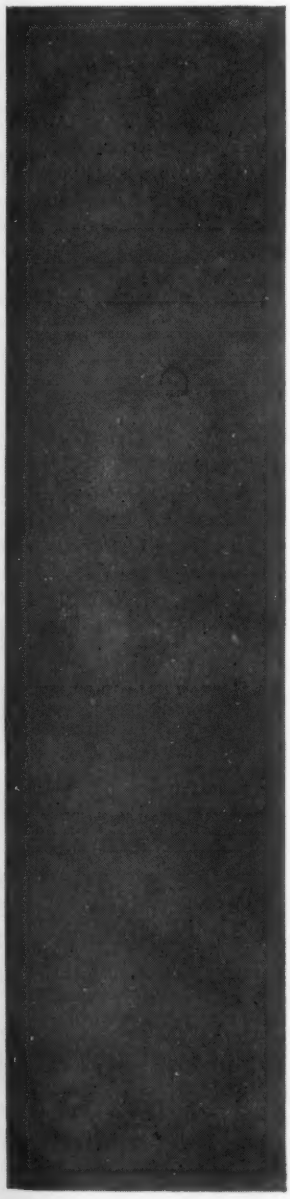

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These young men have already made Autonetics a leader in electronics and electromechanics. For example, they designed the inertial navigation systems for the USS Nautilus and Skate and the monopulse radar system for the Air Force's F-105.

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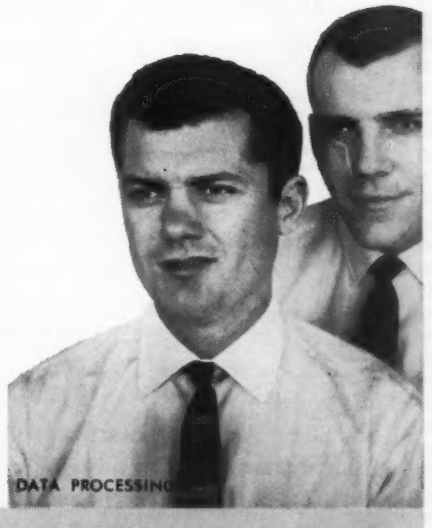

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QUADRATURE REJECTION UNIT

Low-Cost Stable Electromechanical Device For High Gain Servos

An electromechanical unit consisting of a motor, gearhead and feedback potentiometer may seem to be a relatively complex device for eliminating quadrature in high gain servos, bnt according to David Knudsen, Project Engineer of Eastern Air Devices, Dover, N. H. such a unit designed by EAD is compact, rugged and reliable, and is lower priced than electronic devices of comparable performance. Figure 1 shows how the unit is connected in a servomechanism. Mr. Knudsen says this type of configuration is capable of discriminating against quadrature by ratios to 500 or 1000:1. Uulike equivalent electronic devices, he says, the electromechanical quadrature rejection unit is free from drift, and remarkably stable considering its very high rejection ratio.

By its nature, the electromechanical quadrature rejection unit is readily adapted to suit different system requirements. The main field of the servo motor can be matched to any reasonable line voltage, while the control field can be similarly matched to whatever servo-amplifier is used. Control winding power is so low as to constitute a negligible drain on the amplifier, allowing nearly full amplifier output for the servo motor. Gear ratio sets the rate at which quadrature may be varied to track a changing quadrature input. The scale factor (volts/degree) and impedance level of the feedback potentiometer are easily modified In most quadrature rejection units, a resolutionless feedback potentiometer is used to deliver a smooth output without resolution steps which may introduce closed loop instability.

SOURCES OF QUADRATURE EXCITATION

The most significant application difficulty in using the electromechanical unit is to provide a quadrature reference signal of sufficient phase accuracy to balance out the anticipated quadrature error component without affecting in-phase accuracy. The vector diagram of Fig. 2

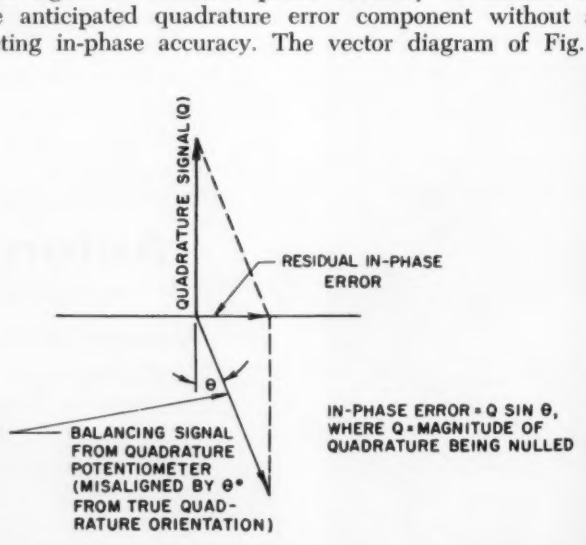
QUADRATURE SIGNAL (Q)
RESIDUAL IN-PHASE ERROR
θ
BALANCING SIGNAL FROM QUADRATURE POTENTIOMETER (MISALIGNED BY θ° FROM TRUE QUADRATURE ORIENTATION)
IN-PHASE ERROR = Q SIN θ, WHERE Q = MAGNITUDE OF QUADRATURE BEING NULLED

Fig 2 Errors introduced by inaccurate quadrature voltage applied to quadrature potentiometer. The in-phase error voltage derived from the quadrature component is balanced out by a repositioning of the servo output, introducing an angular misalignment.

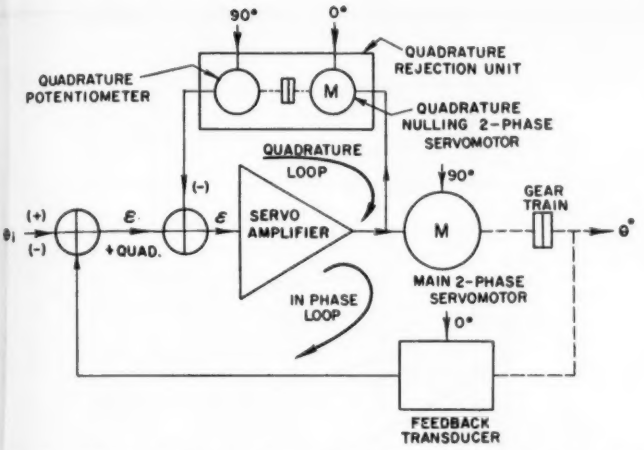

Fig 1 Block diagram of a quadrature rejection unit used in a simple positioning servomechanism. The "degrees" on the figure indicate the relative phasing of the associated voltages. The voltage corresponding to θ_i (input angle) is assumed to be of reference phase (0°) as is the opposing voltage from the feedback transducer (typically a resistance potentiometer) measuring output angle θ_o. The error signal ε, ideally of zero phase angle, ordinarily contains a significant quadrature component which is amplified along with the in-phase error, and applied to the main two-phase servomotor. Since a two-phase servomotor only responds to control signals in time quadrature with its reference phase excitation, the main servomotor is unaffected by the amplified quadrature error component. However, a large quadrature error can saturate the servo-amplifier and reduce the gain of the entire loop with a consequent loss of accuracy and speed of response. The quadrature nulling servomotor does, however, respond to the amplified quadrature error component, and repositions the quadrature potentiometer to balance this out. This is precisely analogous to the main servomotor balancing out the in-phase signal. The quadrature potentiometer is energized by quadrature voltage whose phase angle must be very accurately related to the zero degree reference phase.

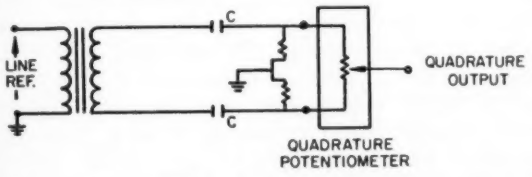

Fig 3 (a) Phase shifting R-C network. The potentiometer of the quadrature rejection unit is included as a resistance element in the design. Temperature errors due to changing circuit parameter, and frequency errors limit the use of this type phase shifter.

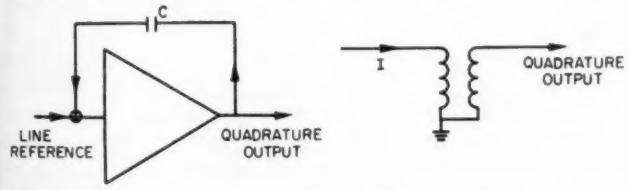

Fig 3 (b) A very accurate 90° shift is obtainable from this high loop gain feedback amplifier.

Fig 3 (c) Where a current source is available an approximately 90° shift may be obtained from a lightly loaded mutual inductance.

illustrates the errors introduced by incorrect quadrature phasing. In systems employing many quadrature rejection units, the additional bulk of a quadrature source is relatively negligible. Fig. 3 illustrates a few of the circuits which may be used to generate quadrature signals and indicate circumstances for their application.

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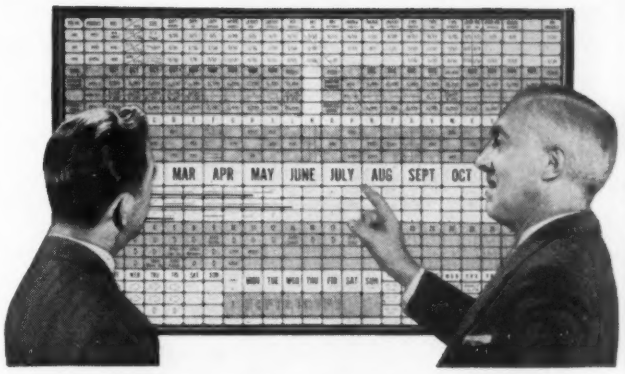

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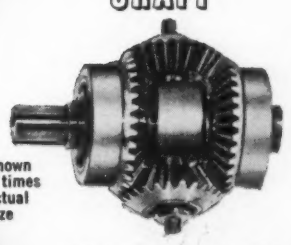

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Figure 2

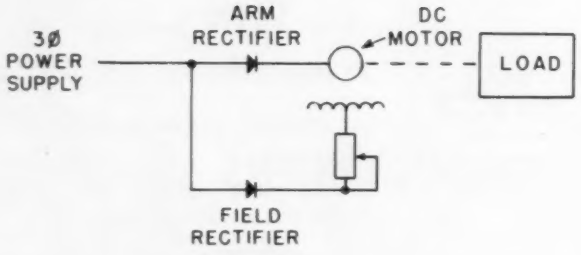

Figure 1

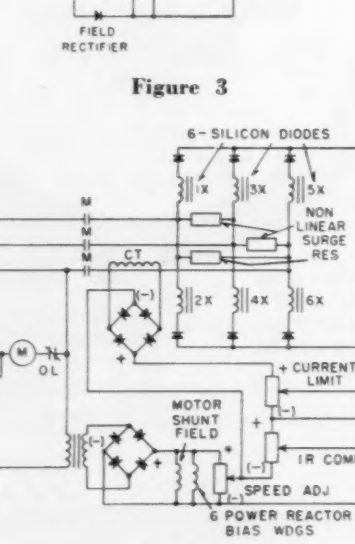

Figure 3

Figure 4

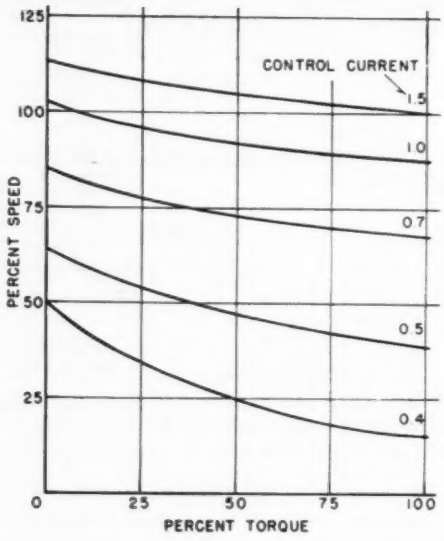

Figure 5

PACKAGED DRIVES

Static Devices and DC Adjustable Drives for Machine Tool Systems

The package-drive concept is growing in popularity amongst machine tool builders. Advantages afforded by completely factory-wired and tested units are obvious, but the tangible benefits show up in the final installed cost of such a drive. The trend in packaged drives is for lower cost, maximum performance and flexibility with minimum physical size. Westinghouse's S.E. Morgan and E.H. Veeder, Systems Control Division, point up some static-power conversion units that represent the major step in this direction. Figure 1 is a schematic for a constant horsepower unit where only the d-c motor field is controlled to provide adjustable speed. Speed control ranges up to 4 to 1 are readily attainable by this arrangement for constant horsepower loads. Figure 2 is an actual unit of this type rated at 75kw at 250 volts d-c. Figure 3 shows how to incorporate the adjustable voltage feature to provide wide speed control ranges by armature-voltage control, power and control magnetic amplifiers. In this case, note that speed control rheostats are provided for both the armature control and motor field control. In this arrangement, a combined constant-torque and constant-horsepower speed range is available. Figure 4 better illustrates how the power magnetic amplifier is used in a complete motor drive. Operating from a three stage source through a circuit breaker affording overcurrent protection, the power reactors and silicon rectifiers are connected directly to the line and the control circuit is energized when the "M" contactor is closed. Together with the silicon rectifiers, the main windings of the power reactor are connected in a three phase bridge circuit. Nonlinear resistors protect the silicon diodes against voltage surges and, in addition, voltage dividing resistors are connected across each diode to assure the equal distribution of a surge throughout the circuit. Power reactors are made as simple as possible by utilizing only a bias and speed control winding.

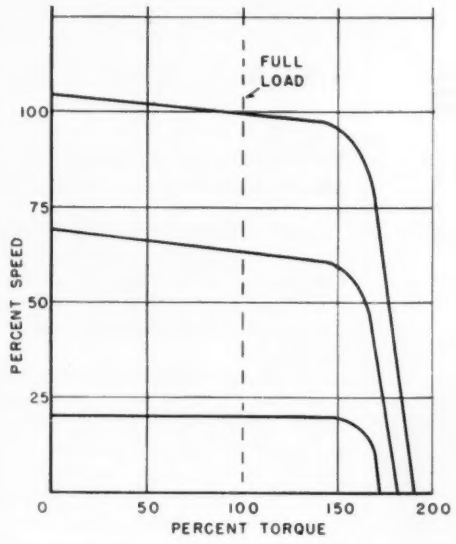

Figure 6

All other functions are controlled by a magamp. Figure 5 shows the speed torque curves of a simple system without a regulator, and points up the inherent droop of the drive is too great for most applications thus calling for some form of regulation. Figure 6 shows the curves when a regulator has been added to the system. With the compensation set for essentially flat regulation at 20 percent of top speed, the drive performs with regulation within about plus or minus 5 percent of top speed. Figure 7 shows the typical drive unit (front and rear views) which is rated at 40 hp with the blower or at 30 hp without the blower. Front view shows the major components from top to bottom: control magnetic amplifier panel, a-c control panel with incoming line circuit breaker and starter, and at the bottom three of the six power reactors mounted on the cabinet floor. In the rear view, again from top to bottom, we see the d-c and constant potential exicter for control circuits and motor field. The remaining three power reactors are at the bottom of the cabinet.

Principal advantages that industry can expect from drives of this type are these:

- High efficiency of the over-all system; efficiency above half speed is in the range of 70 to 83 percent. In contrast, typical efficiency for an m-g set ranges from 63 to 73 percent.
- Low maintenance, long life, and extreme reliability of the power package. Magnetic amplifiers, power reactors, and silicon diodes provide the benefits now established as characteristic of static control components.
- Elimination of the direct-current contactor. Since the opening and closing of the power circuit is performed ahead of the rectifiers, the advantages of a-c interruption are made available to the user.
- Compactness of design requires but minimum floor space.
- Elimination of need for reduced-voltage a-c starters. These are never required since inrush currents are low because of the fact that the power circuit is closed on unsaturated reactors.

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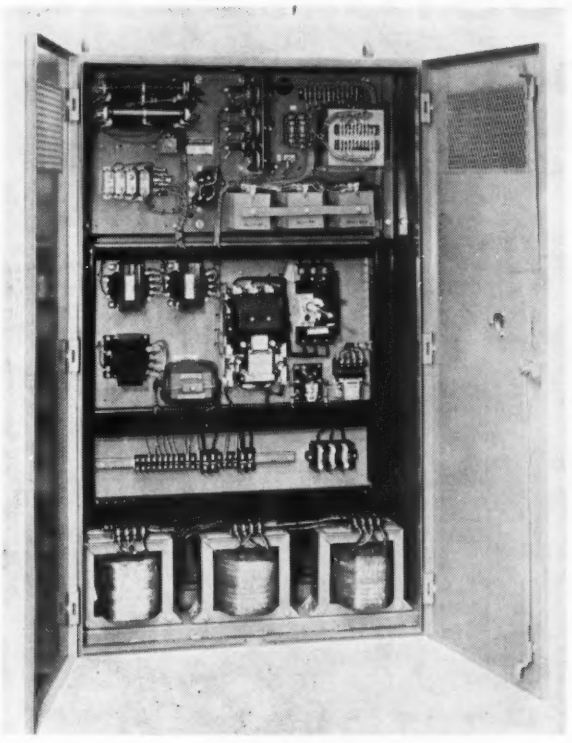

Figure 7a

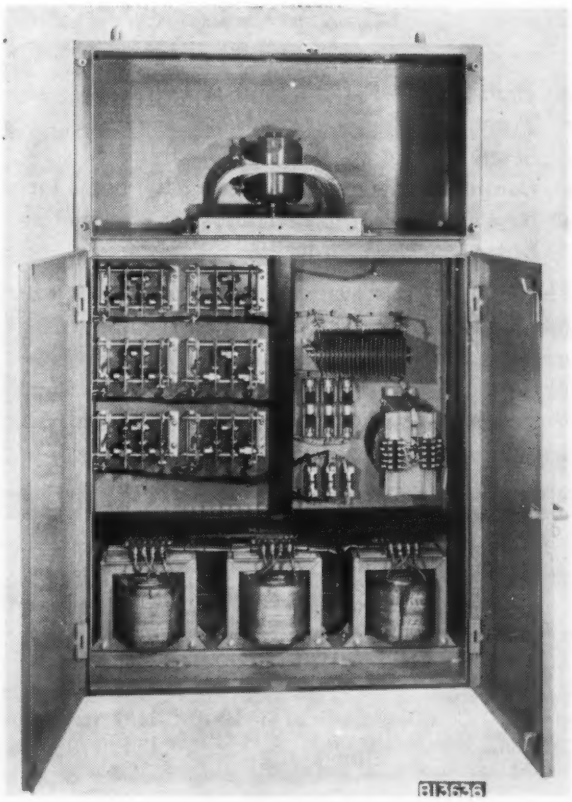

Figure 7b

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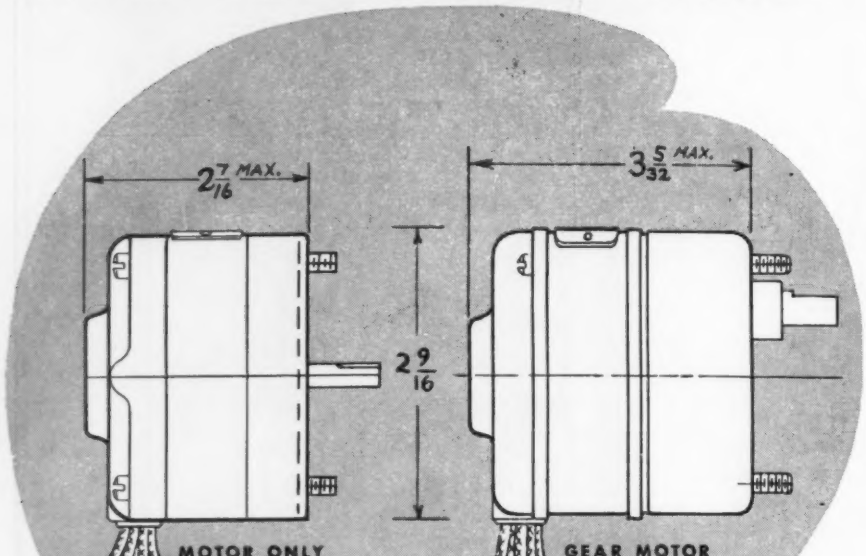

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AIRBORNE DIGITAL COMPUTER

Miniaturized Unit Simplifies Aircraft and Missile Navigation

A small lightweight airborne, multifunctional, digital computer that accurately solves most navigational problems in both aircraft and missiles is now available from Librascope, Incorporated, of Glendale, California.

Silicon-transistorized throughout, the new AN/ASN-24 is immune to a wide range of environmental extremes. For this reason, it is highly suitable not only for solving navigational problems in high Mach number aircraft, but also, because of its extremely small size and weight and rugged design, for guidance applications in a wide range of missiles.

The ulta-lightweight computer accepts inputs from both present as well as planned navigation aids to provide self-correcting dead-reckoning and celestial navigation. Key feature is its capability of accepting new navigational aids as they are developed. The AN/ASN-24 can serve as the prime module for military and commercial navigation systems. Besides its navigational role in high performance aircraft it is also ideally suitable to guidance functions in missile systems, mainly due to its degree of adaptability to inertial, Doppler and celestial sensors.

The new AN/ASN-24 handles the data from TACAN, celestial, inertial and Doppler information, radio, true airspeed systems and heading instruments, in one computer unit, at a fraction of the weight and in the most compact package. Information may also be fed to the computer manually during the flight.

Fig. 1 Control console for AN/ASN-24 Computer displays latitude and longitude information. Design permits pilot to enter pertinent information before or during flight and to request specific information from the computer.

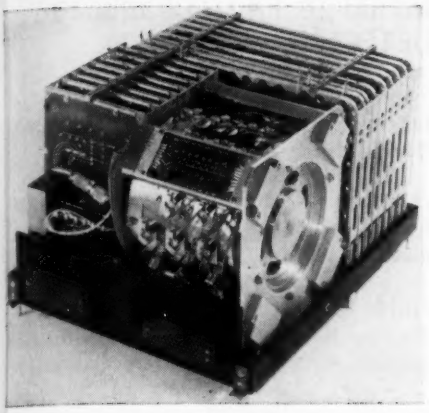

Fig. 2 Magnetic memory drum (foreground) stores digital impulses as 25 bit words. Rotary at 6000 rpm. The drum has 32 channels, each holding 64 words. Miniaturized unit weighs only 32 pounds and occupies bare 0.55 cu. ft.

Highly reliable, all circuits have been designed well below the capacity rating of the components. Derating of components pays off in maintenance, since precision checking and balancing of replacement components is not necessary. The computer provides aircraft position at any particular time from dead-reckoning, navigation ground systems, celestial fixes, or any combination of these. A credibility criteria programmed into the memory permits the computer to select the "best" input information from the sensors. Data obtained from the various sensors is carefully "weighted" to provide maximum accuracy in the computed results. The digital computer will continuously subject itself to test problems designed to determine whether it is functioning properly.

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Sequential-to-sequential Buffer Storages, based on coincident-current magnetic storage elements are designed to implement digital data transfer between systems or equipments that are asynchronous, or have different data rates, for collection or regular or aperiodic data from tapes, analog-to-digital converters and other digital sources.

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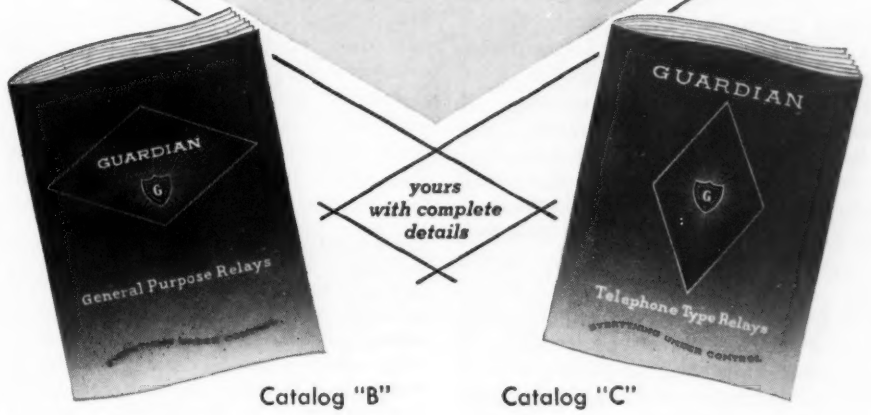

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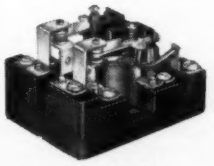

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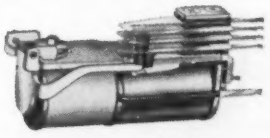

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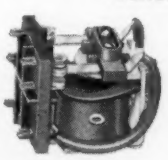

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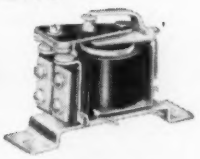

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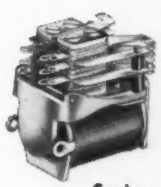

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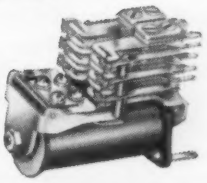

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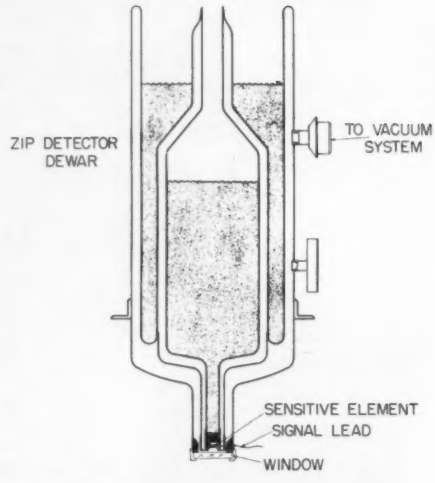
INFRA-RED INSTRUMENTATION

New Detector Gives Fast Response To Cool Body Radiation

A previously unavailable combination of sensitivity, speed of response, and broad spectral coverage is claimed for a new infrared-red detector by Perkin-Elmer Corp in Connecticut. Developed at Naval Research Laboratories, the P-E 536-1 "ZIP" Detector opens the door for significant advances in military, research and industrial applications of infra-red instrumentation.

According to scientists at the Naval Research Laboratory, the "Perkin-Elmer Detector represents the first commercial version of a new generation of fast, photo-conductive detectors for the 8-14 micron region". This feature permits effective detection of the small infra-red radiation (heat) from all bodies, even those cooler than normal climatic temperatures. ZIP detectors (the term ZIP derives from its laboratory designation as a zinc-impurity-photoconductor) time constant is less than .01 microseconds. This unusual speed of response extends the capabilities of infra-red for rapid scanning applications and observation of very fast phenomena.

Model 536-1, the basic version, utilizes a zinc-doped germanium photoconductor. Use of this bulk-type photoconductor permits accurate control of cell conductivity and other material parameters to ensure specified performance of the unit. In addition to military applications such as reconnaissance and air warning, the new development makes possible more extensive use of infra-red instrumentation in such areas as navigation, space exploration and laboratory research. The new detector's high speed of response and sensitivity to infra-red radiation from bodies at room temperature or cooler also makes it suitable for use as a process-line regulatory device.



High efficiency of the unit results from cooling it to the temperature of liquid helium, shielded by liquid nitrogen. The cryostat, having a holding time of 24 hours, consists of a double dewar flask with overall dimensions of 18 inches in length and 6 inches in diameter. Sensitive element is in the tip of a 1¼ inch O.D. snout at the base of the cryostat.

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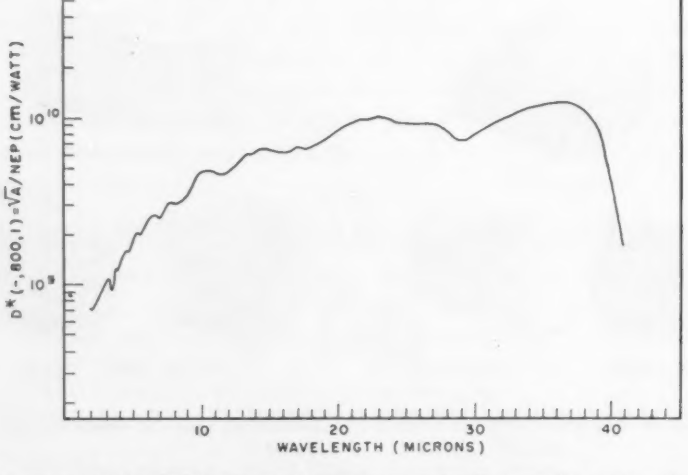


The whole range of the ZIP's spectral response extends from 2 to 40 microns with peak sensitivity occurring at about 37 microns. Extreme sensitivity of the detector is indicated by its D* factor of 4 x 10^9 cm/watt. "D*" (500 degrees K, 800 cps, 1 cps) is a standard employed to remove the factor of a detector's size from the measurement of its sensitivity; it is defined as the square root of the detector's sensitive area in square centimeters divided by the Noise Equivalent Power in watts.

INFRARED PHOTOCONDUCTOR DETECTOR

Infrared Radiation Varies Electrical Conductivity of Gold-Germanium

A new ultra-sensitive detector containing a germanium-gold medium that changes its ability to conduct electricity when radiation such as infrared or visible light strikes its surface responds to less than one-twentieth of a billionth watt of infrared radiation. Changes in the intensity of infrared radiation reaching the photoconductor are converted into changes in the amount of electric current flowing through it. Germanium is made sensitive to infrared by a "doping" process during which an impurity, gold, is added.

Developed by Dr. Max Garbury, J. R. Hansen and T. P. Vogl, of Westinghouse Research Laboratories in consultation with Dr. Henry Levinstein of Syracuse University, the detector, known as a photoconductor detector, is the most critical component of a complete infrared system. Dr. J. W. Coltman, manager of the laboratories' electronics and nuclear physics department said that, in addition to its sensitivity, a major advantage of this gold-doped germanium detector over other varieties is its response to the longer wavelengths of infrared. Longer wavelengths, corresponding to lower temperature, are the most difficult to detect. Yet these often are the very wavelengths we want most to see.

There is little difficulty observing a red-hot object with a relatively insensitive infrared detector. Such an object has a temperature in the neighborhood of 1500 degrees and emits most of its infrared radiation near the comparatively short wavelength of three microns, or 100 millionths of an inch. It is an entirely different matter, however, to detect the same body at the temperatures of the human body, 98.6 degrees. At this low temperature, peak infrared radiation has tripled to a wavelength of about nine microns, while the total emitted energy has fallen to less than one-hundredth of its previous value.

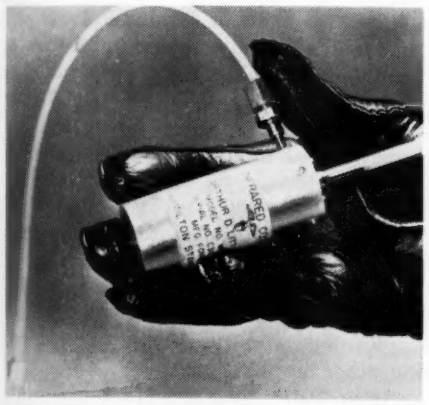
The problem was to devise a detector that responds to feeble, long-wavelength radiations; has good sensitivity throughout the range of infrared frequencies; and reacts rapidly enough to be practical and useful.

This doped germanium detector is highly sensitive to infrared up to a wavelength of 10 microns corresponding roughly to the peak radiation at room temperature. At the same time, it is about 10 times faster than any previous photoconductor detector.

Dr. Coltman said that the new detector is so fast in its response that special laboratory apparatus had to be developed to test its speed. The apparatus, a mechanical light chopper, breaks infrared into pulses only a few billionths of a second long. Pulses, reflected to the surface of a detector, show its "time constant" to be two-tenths of a millionth of a second.

Because the sensitivity and frequency response of a photoconductive infrared detector is increased by operating it at low temperatures, the detector is cooled to a temperature of −320°F by surrounding it with liquid nitrogen in a special container.

Circle No. 80 on Inquiry Card



The ADL min-IR Cooler is a compact, low-pressure, closed-cycle refrigeration device developed for use with infrared detection equipment. It can maintain such detectors at temperatures as low as minus 350 degrees Fahrenheit.

New Refrigeration Technique Increases Infrared Sensitivity

A tiny cooling device which superchills infrared detection equipment to 60° Kelvin (−350F) by a new refrigerating technique may prove to be a significant achievement in support of U. S. military and civil aviation. The eight - ounce min - IR - cooler resulted from a pioneering two-year research project into extreme low temperature equipment conducted by Dr. Howard O. McMahon and William E. Gifford at Arthur D. Little, Inc., Cambridge research and engineering company.

Development of the system for infrared applications is being conducted by ADL and Hamilton Standard, Div. of United Aircraft Corp., Windsor Locks, Conn. The latter holds an exclusive license from ADL to manufacture the min-IR-cooler for infrared applications only. Ideal for airborne operation in missles or airplanes, the present closed-cycle detection system is designed to weigh less than 20 pounds. Further development is expected to reduce this weight to less than ten pounds. In operation, helium gas expands from 300psi in a quarter-inch-diameter cylinder, two inches long. A tiny plastic piston is the only moving part of the unit below room temperature. The cold end of the tube refrigerates an infrared cell to 60° Kelvin.

Designers pointed out that cooling infrared detectors to extremely low temperatures increases their sensitivity and makes them responsive to a wider range of IR wave lengths. This makes it possible to detect small temperature differences between the "target" and its surroundings. An air-borne IR detector with a min - IR - cooler, for instance, would be able to detect the presence of an aircraft or missle from a great distance. The need for a miniature, reliable refrigerator for extremely low temperatures has been recognized for several years. No completely satisfactory system has been devised before this. The same principles used in the min-IR-cooler are being applied by ADL to other areas of low temperature.

Circle No. 103 on Inquiry Card

Printed Circuit Assembly Tool Forms Component Leads

Precision forming of component leads for printed circuit assembly can now be accomplished in just three seconds, and without damage to the component, by means of an inexpensive hand tool. The device, called Leedform, accommodates all axial-lead components, such as diodes, capacitors, chokes, rectifiers and resistors. Designed to cut reject rates and speed assembly, it was developed for Northrop Aircraft to solve problems in component damage. Through its stress-free forming action, the tool overcomes one of the biggest problems in printed circuit assembly —that of accidental deformation of leads within delicate components, a frequent result of using pliers. The new forming method also increases the shock and vibration resistanoe of the finished assembly. By making circular, rather than angular bends in the leads, the tool creates a spring action between component and printed circuit board which has enabled assemblies to withstand vibration tests to 250G. The spring action of the lead also holds the components in place during dip-solder operations, thereby eliminating the production step normally required to keep components from falling off the printed circuit board. A. G. Barstow Co., South Gate, Cal.

Circle No. 252 on Inquiry Card

High Temperature Terminal Speeds Systems Installation

Design engineer at the Thomas & Betts Co. checks against a furnace light the first self-insulated electrical terminal for high temperature applications in aircraft, missiles and electronic wiring. Present high temperature terminals consist of two components, and are time-consuming to install. The new terminal is of single-piece design, and is installed in less than half the time. According to T & B, savings in labor costs can be substantial even where a small number of terminals are to be installed.

T&B uses Teflon as the material for the terminal's sleeve, which covers the terminal barrel and a portion of the conductor to be terminated. It is chiefly the use of Teflon that allows for applications to 500 F for indefinite periods and to 600 F for short periods. The precise compression in the Teflon and the intimate contact between wire and terminal made by the proper hand or power compression tool remain permanent despite constant high temperatures.

Circle No. 133 on Inquiry Card

New Aluminum Joining Method

A zinc soldering process for joining aluminum to itself and other metals is expected to broaden the light metal's use in refrigeration, automotive, air conditioning, and electrical industries. Exhaustive tests by Aluminum Co. of America indicate the zinc technique offers the best method for making sound, corrosion-resistant soldered joints. Alcoa engineers also found the process to be superior to brazing for several applications. When employed with specially developed Alcoa joining products, the zinc soldering process is especially suited to bonding thin complex sections, including heat exchangers of all types. Other promising applications are indicated by recent research: metallurgical bonding of aluminum spirally wrapped or plate films to aluminum, copper or steel tube, and bonding dissimilar metal transition joints.

Circle No. 234 on Inquiry Card

NEW WIRE INSULATION

Flexible Inorganic Films For High-Temp Electrical Insulation

Many potentially important applications of electrical circuitry at high temperatures are presently hindered by the lack of high quality flexible wire insulation. Recent discoveries at Bell Tel Labs indicate that fluoride coatings can be formed on copper, aluminum and other metal wires which will provide exceptionally high insulation value at elevated temperatures while retaining flexibility and freedom from porosity.

According to a paper by Drs. Steward S. Flaschen and Paul D. Garn, presented to the May meeting of the American Ceramic Society in Chicago, the insulating coatings are formed directly on freshly cleaned copper or aluminum by exposing them to oxidizing carriers of fluorine such as hydrogen fluoride or elemental fluorine at temperatures from 300C to 600C. The thickness of the resulting copper fluoride and aluminum fluoride films depends on the temperature at which they are formed, the concentration of fluorine and the time of exposure. Aluminum forms a fluoride film one micron thick in a few minutes at 550C. These films remain adherent when bent repeatedly at 90° angles.

Electrical insulation values are very high for both copper and aluminum films, being in the order of 10^{10} and 10^{11} ohms at room temperature for films in the order of 1 to 2 microns thick, between probe electrodes ¼-in in diameter. The films retain their excellent insulating properties at high temperatures. For example, aluminum fluorine and the time of exposure. about 7 x 10^8 ohms at temperatures as high as 500C.

The aluminum fluoride films show excellent resistance to oxidation even above 600C. They also show no tendency to hydrate or dissolve on exposure to high humidity. The insulation does not break down even at 450 volts at 500C.

The best organic insulating coatings cannot be used continuously above 300C. Inorganic insulators are generally porous and non-flexible, although some may be used as high as 830C. Insulating fluoride coatings should be satisfactory almost up to the melting point of the conductor.

This new approach to insulating could provide the answer to some of the problems in missile re-entry guidance systems, as well as other more earthbound high temperature electrical applications. The technique is not limited to copper and aluminum according to its inventors, but can be used to form thin flexible films on other metals as well.

Aluminum-Teflon For Gaskets And Conductors

A new gasketing material combining the best features of aluminum and Teflon for use as an extra-thin gasketing material and as an insulated flat conductor in electronic components is now available from American Machine & Foundry Company.

Called AMFoil, the new product consists of aluminum foil with duPont's Teflon resin cast on one or both sides then fused at 900F to form a permanent bond. Foil thicknesses range from 0.0002″ to 0.012″ and the Teflon coatings range from 0.00006″ to 0.001″. Ultra thin AMFoil is used in electronic applications and the thicker types are for other applications.

As an extra thin gasketing material, AMFoil is resistant to wide temperature variations and has high tensile strength. It makes reliable diaphragms and gaskets for missile, jet engine components, engine blocks and other mechanically bolted and gasketed equipment. Also, its lighter weight and smaller volume can be utilized for miniaturization of electrical components.

Other possible applications of AMFoil may be in cryogenics research and instrumentation. AMFlex Products, American Machine & Foundry Co., New York, N.Y.

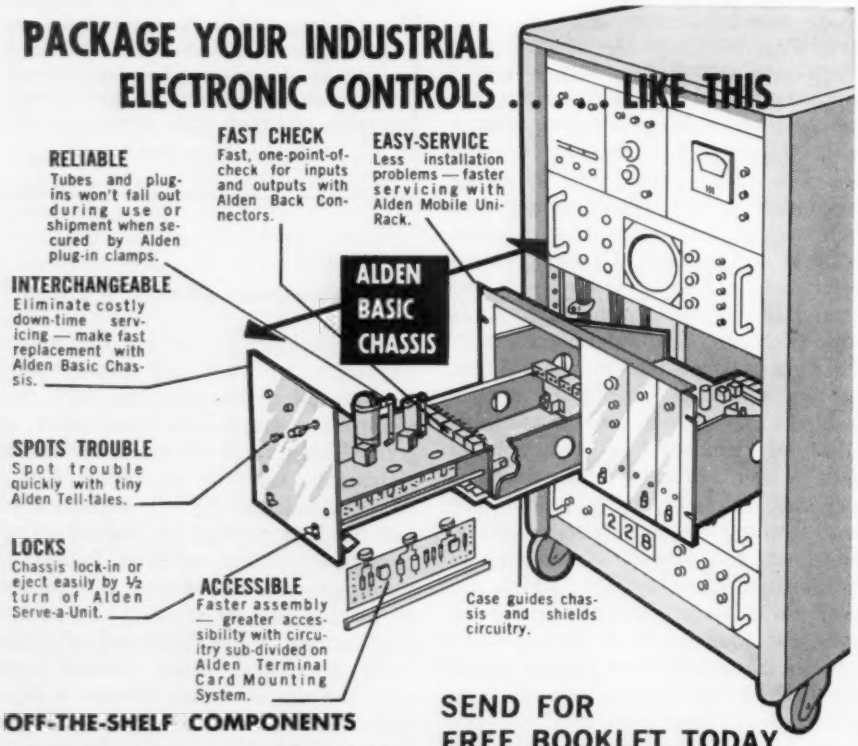
Circle No. 118 on Inquiry Card

Free Sample: Liquid Lockwasher

A liquid lockwasher "fits" all sizes of threaded fasteners, eliminates press fits and seals pressure joints. A polyethylene squeeze capsule contains Locktite sealant—a thin liquid polymer that hardens only when confined between close-fitting metal parts; catalytic action of the metal surfaces, aided by absence of air, causes the sealant to harden into a tough heat-and-oil-resistant bond. One drop in the threads locks the mating parts together. American Sealants Co., Hartford, Conn.

For your free sample:
Circle No. 139 on Inquiry Card

PACKAGE YOUR INDUSTRIAL ELECTRONIC CONTROLS . . . LIKE THIS


RELIABLE
Tubes and plug-ins won't fall out during use or shipment when secured by Alden plug-in clamps.
FAST CHECK
Fast, one-point-of-check for inputs and outputs with Alden Back Connectors.
EASY-SERVICE
Less installation problems — faster servicing with Alden Mobile Uni-Rack.
INTERCHANGEABLE
Eliminate costly down-time servicing — make fast replacement with Alden Basic Chassis.
ALDEN BASIC CHASSIS
SPOTS TROUBLE
Spot trouble quickly with tiny Alden Tell-tales.
LOCKS
Chassis lock-in or eject easily by ½ turn of Alden Serve-a-Unit.
ACCESSIBLE
Faster assembly — greater accessibility with circuitry sub-divided on Alden Terminal Card Mounting System.
Case guides chassis and shields circuitry.

OFF-THE-SHELF COMPONENTS

Now — you can lay out and package a unit or system — breadboard to production — with standard "off the shelf" Alden Electronic Packaging components for plug-in, modular construction. Especially suited for building engineering models, prototypes, custom instruments, test gear, controls, etc. Used widely by private and government labs, universities, and industry.

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CIRCLE 39 ON INQUIRY CARD

MATERIALS

Protective Packaging Material

Fiberglas protective packaging material, designed to protect a wide variety of objects from damage and from rapid changes in temperature in transit, retains all its desirable characteristics in temperatures from minus 120 degrees to 375 degrees. These are: high compression resistance, damping and thermal efficiency, extreme resilience, fire retardance, non-corrosiveness and resistance to fungus and rot. The new product conforms to all the requirements of Military Specifications Mil-C-7769 and is available in four types: soft, medium soft, medium firm and firm. It can also be molded to any shape. Owens-Corning Fiberglas Corp., Toledo, O.

Circle No. 136 on Inquiry Card

Stainless Steel Tubing

Small tubing drawn from PH 15-7 Mo, a precipitation-hardening stainless steel possessing outstanding mechanical properties at elevated temperatures, is described in Special Analysis No. 120 published by Superior Tube Company. Mechanical properties show tensile strengths up to 205,000 psi at 600F and 130,000 psi at 1000F in one of the heat-treated conditions. However, the tubing made from the material is readily formed. Suggested applications include aircraft structural parts, instrument parts and high-pressure hydraulic lines. Copies of the report are available free on request by writing to Superior Tube Co., 1898 Germantown Ave., Norristown, Pa. or

Circle No. 135 on Inquiry Card

Glass-Teflon Insulation In Sheet, Rod and Tubes

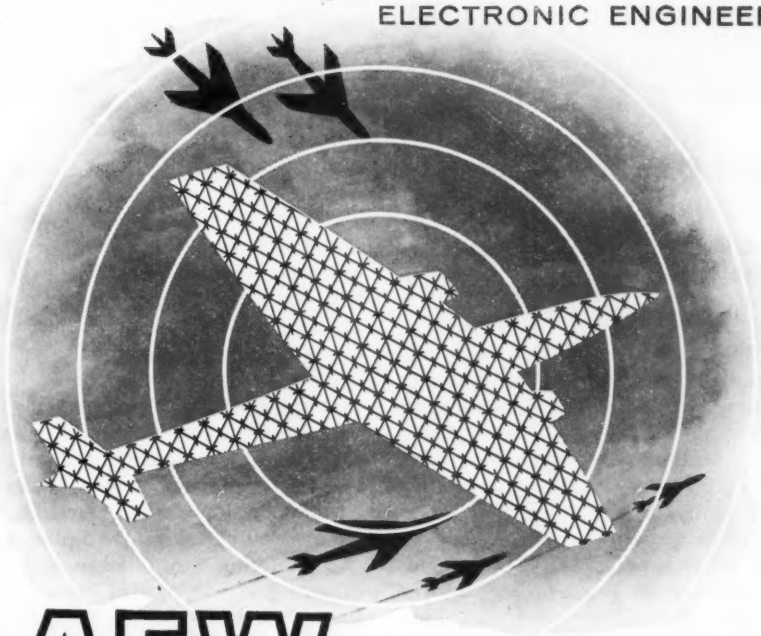
A glass-Teflon electronic insulating material for use in high temperature applications is available as copper clad sheet and as rod, tubes and flat sheets.

Designated Duroid 5870, the dielectric material is composed of micro-glass fibers uniformly coated with Teflon. The material was developed primarily for use as a high temperature circuit base stock, missile antenna dielectric and as microwave strip insulation.

To assure proper functioning at elevated temperatures, the adhesive commonly used to bond copper to base stock has been eliminated in Duroid 5870 copper clad. Instead, a film of Teflon 100X is used as a bonding agent. Rogers Corp., Rogers, Conn.

Circle No. 119 on Inquiry Card

ELECTRONIC ENGINEERS



AEW with the automated voice of command....

ANOTHER OF THE MANY ADVANCED PROJECTS ATTRACTING ENGINEERS TO GENERAL ELECTRIC'S LIGHT MILITARY ELECTRONICS DEPARTMENT

Light Military is developing a new concept in Airborne Early Warning and Control which will provide protection for a mobile unit by detecting enemy aircraft at unprecedented ranges, tracking, adapting itself to changing combat situations, and transmitting tactical data *automatically* to combat information centers. The system will match a 3-Dimensional radar with novel correlation techniques and an automated data handling system which – for the first time – will practically eliminate Man from the control loop.

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MICROWAVE DEVICES	SERVOMECHANISMS	DATA PROCESSING & DIGITAL TECHNIQUES
IF AMPLIFIERS	TRANSISTOR CIRCUITRY	INFRARED
RADAR RECEIVERS & TRANSMITTERS	TRAVELLING WAVE TUBES	VIBRATION & SHOCK

Forward an outline of your experience or your resume in strict confidence to: Mr. W. Gilmore, Dept. 29-MF

LMED

LIGHT MILITARY ELECTRONICS DEPARTMENT

GENERAL ELECTRIC

FRENCH ROAD, UTICA, NEW YORK

CIRCLE 40 ON INQUIRY CARD

Transistor Amplifiers for D. C. Signals

Although amplification of a d-c signal is a simple requirement, the choice of amplifier is a difficult problem. It is difficult because most of the many relevant papers published deal with amplifiers with only narrow fields of application. N. V. Phillips' Gloeilampenfabrieken of Eindhoven, The Netherlands, published a paper in their *Electronic Applications* that details a sufficiently complete range of d-c amplifiers to make the choice for a particular job fairly simple. The table on this page summarizes performances of the basic type of direct-coupled and chopper types of amplifiers.

In this analysis no attempt was made to select or match any of the transistors in the amplifiers; the tabulated results can therefore be considered fairly typical and reproduceable. Component tolerances were not considered because the amplifiers do not represent the best performances attainable.

NOTES ON THE USE OF THE TABLE

An amplifier for a particular application should be chosen after careful consideration of the required properties. For example, if milliamps are to be amplified, do not design a circuit with a drift of millimicroamps.

Direct-coupled amplifiers have a preference for either a very high or a very low source resistance if minimum drift is to be achieved. The recommended source resistance varies from 300 kilo ohms and above to low resistances of the thermo-coupled type.

The circuits examined were designed to give generally useful values of gain. If you need greater amplification, such as from millimicroamps to an ampere or so, you can connect two or more amplifiers in cascade.

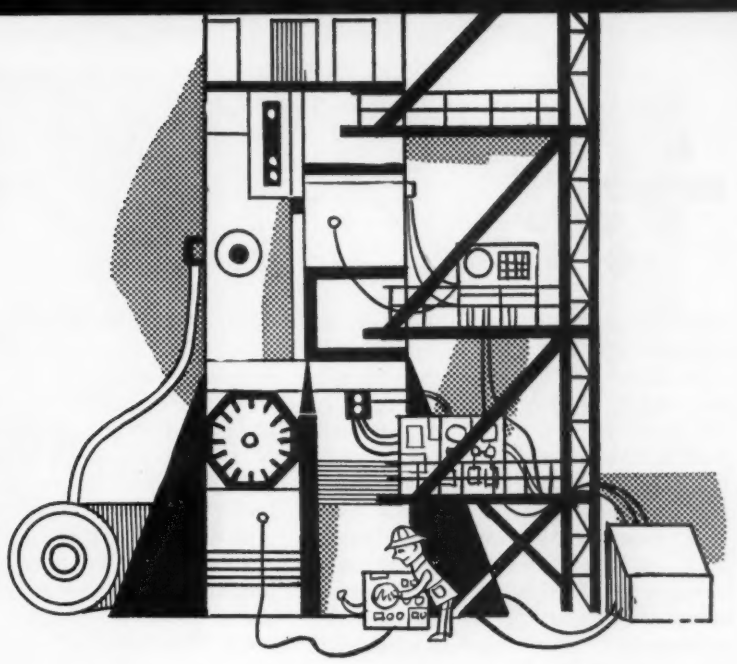
Drift figures for the various semiconductor types are quoted in terms of changes in temperature; a factor of improvement of about 30 can be achieved for a direct-coupled amplifier by simple stabilization of the temperature. The supply must be correspondingly stabilized to realize the full advantage of temperature control. Silicon transistors though offering a great improvement for current set amplifiers (where the source resistance is much greater than the transistor input resistance) still do not solve the problem completely because they do not offer any advantage over germanium transistors for signals from low-resistance sources.

Where chopper types are concerned, the mechanical chopper still offers the best performance in terms of amplification. You can get comparable results with a temperature-controlled transistor chopper. The double complication involved (with temperature control) makes the idea unattractive at present because the transistor chopper also suffers from transient effects for which there is no simple solution. Alternatively, the less temperature-sensitive silicon transistors offer promise for chopper applications, although practical figures are not yet available.

There are some forseeable developments in the improvement of large bandwidth transistor amplifiers. One technique is to control an unstabilized direct-coupled amplifier using an auxiliary drift free narrow-band d-c amplifier. No practical circuit of this type has yet been published; the assessment of the performance of such a system is difficult. It might be simpler to stabilize the ambient temperature of the transistor to a high degree, in an amplifier of long-tailed-pair type with a silicon transistor input stage.

Design information	Direct-coupled amplifiers					Chopper-type amplifiers		
	Germanium transistors	Silicon transistors	Long-tailed-pair germ. transistors	Long-tailed-pair silicon transistors	Long-tailed-pair germ. transistors temperature controlled	Silicon-diode chopper	Transistor chopper	Mechanical chopper
Gain	500 (current)	1000 (current)	500 (voltage)	500 (voltage)	500 (voltage)	1000 (current)	10 000 (voltage)	60 000 (current)
Zero drift	4 to 8 μA/°C	0.1 μA/°C	0.1 mV/°C	0.1 mV/°C	5 μV/°C	2.5 mμA/°C	0.5 mμA/°C	2 to 3 μV/hour
Input for full scale output	2 mA	5 μA	10 mV	10 mV	10 mV	1 μA	1 μA	50 μV
Full scale output	1 A	5 mA	5 V	5 V	5 V	1 mA	5 V	200 μA
Specified source resistance	>3 kΩ	>300 kΩ	<100 kΩ	any	<100 Ω	any	any	any
Input resistance	250 Ω	1 kΩ	5 kΩ	5 kΩ	5 kΩ	10 kΩ	500 kΩ	15 kΩ
Output resistance	15 Ω	2 kΩ	25 Ω	1 kΩ	25 Ω	—	2 kΩ	2 kΩ
Load resistance	0.1 Ω	100 kΩ	5 kΩ	5 kΩ	5 kΩ	150 Ω	200 Ω	400 Ω
Power supplies required	−12 V tap at −8 V 1.3 A for full scale output	24 V at 60 mA	12 V at 20 mA	12 V at 20 mA	12 V at 20 mA and 120 V at 0.3 A for temperature control	−12 V at 30 mA	−30 V at 40 mA; −2V; +15V at 30mA; +16.5 V at 15 mA; +20V at 0.2 mA	−6 V and +3 V at 10 mA and −12 V at 18mA for chopper

COMPONENTS 4 DIGEST



ENVIRONMENTAL TESTING—Part 2

Part I of Environmental Testing (ELECTROMECHANICAL DESIGN, March 1959) examined the more important military specifications and compared their requirements. The different kinds of tests with the general nature of the failures that occur were related to components of the type considered in the Components Digest series. The role of environmental testing as an integral portion of a devlopment program on a new component or system was emphasized.

In this next part (Part II) additional tests are described, further details are provided on tests already covered, and a description is presented of environmental testing equipment with particular reference to recent developments emphasizing severe environments. Because environmental testing is generally sub-contracted locally for best coordination, the Buyers' Guide in this digest lists Test Laboratories on a regional basis.

BACKGROUND INFORMATION

In January 1958, RCA published the 3rd part of a 3-part study (WADC Tech. Report 57-456) by R. A. Ditaranto and J. J. Lamb on "Preliminary Investigation of Hyper Environments and Methods of Simulation." Their purpose was to:

- collect and assemble present-day knowledge of environments at altitudes above 75,000 feet to 400 miles;
- determine the effects of operating in such environments;
- indicate how the environments may be simulated in test chambers and;
- study the incorporation of these test chambers into test facilities so that subsystems, equipments and components may be tested in the environments in which they will be required to perform.

RCA proposed a centralized type environmental laboratory with an overall cost of $5,417,000 with a total area of 46,500 square feet to be staffed by 60 men.

In a follow-up study next October, Ohio State University will report on planetary and interplanetary environments and methods of simulation: these two reports, made for WADC will ultimately result in an Air Force Facility tentatively designed as Hyper Environment Multiple Research Facility in about 3 years from now.

WADC has also recently awarded United States Testing Company, Inc., Hoboken, N. J., a one-year contract to explore the feasibility of combined-environment testing, to seek more realistic test conditions for electronic components. U. S. Testing says that current practice in component testing utilizes a series of single-environment exposures (or, at most, a simple group of environments), usually in a predetermined order. This test method they say rarely matches actual service conditions, where several environmental factors operate simultaneously. By combining several environmental factors (such as alternating high and low temperatures, coupled with vibration, shock, and acceleration; or alternating high and low temperatures plus sand and dust), they hope to make several important gains.

- Components will be subjected to tests more nearly matching actual service.
- Test time (and costs) will be reduced. With single-exposure testing, the components go through tests "Indian File"; combined-environment testing will handle many tests during one exposure.

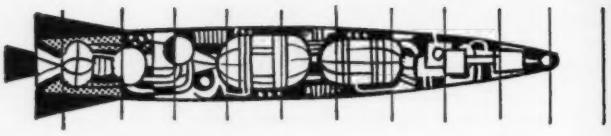
As far as possible, testing will be done with existing equipment, modified to suit these new needs. In this way the results will be applicable throughout the testing industry without expensive acquisition of new facilities. However, until such overall facilities are operational, most environmental testing will still take place in companies throughout the country and individual component and subsystem manufacturers will still be subjecting their hardware to hyper environmental tests outside of a central operation. In this section, we detail the highlights of equipment and trends recently brought to our attention as a result of an industry survey.

Radio Interference

An important aspect of the functioning of electronic equipment which is sometimes construed as part of the environmental characteristic is radio interference. The common sources of interference in aircraft receivers are listed in Table I. As stated in the most commonly referenced military specification on the subject, MIL-I-6181B dated May 29, 1953,

"Electrical and electronic equipment

COMPONENTS DIGEST



shall operate satisfactorily, not only independently, but also in conjunction with other such equipment which may be placed nearby. This requires that the operation of all such equipment shall not be adversely affected by radio interference voltages and fields reaching it from external sources, and also requires that such equipment shall not, itself, be a source of radio interference which might adversely affect the operation of other nearby equipment." The same specification lists design guides for minimizing interference as summarized in Table II.

Radio interference is generated in two distinct ways: conduction back through common lines, and by radiation. It may occur as a result of poor frequency selectivity, the generation of spurious frequencies or some similar mechanism or it may occur as a consequence of noise generated by d-c motor brushes, arcing contacts, flow of leakage currents through bearings of rotating equipment, leaky capacitors or arcing resistors, where generated noise covers an extremely wide band.

MIL-I-6181B describes interference measurement in great detail, listing the specific instruments required to cover the range from 0.15 to 1000 mc. Interference limits are given as a function of frequency for both conducted and radiated interference. The tests cover both the generated interference limits and the susceptibility limits.

Interference is generated by coupling between a source of interference and a piece of communication equipment. Coupling may be direct, through stray capacitance or common resistance, or indirect by induction or radiation. These coupling paths can be surprisingly complex. Common ground wires and bonding straps, may have appreciable RF resistance even though ohmic resistance is negligible. Resistance coupling exists between all components energized on the same power line. Unless adequate filtering is provided, this common line resistance may result in substantial interference. Rules of good wiring dictate the use of a single common ground point in electronic subassemblies, and single bonding straps from the subassemblies to the equipment ground. Separate grounds are commonly used for power circuits. Ground loop and chassis currents, resulting from multiple ground points, are to be avoided.

TABLE I

Categories of Radio Interference in Aircraft

INTERFERENCE CREATED OUTSIDE AIRCRAFT

1. Atmospheric Static.
2. Precipitation Static.
3. Man made external interference such as from adjacent vehicles.

INTERFERENCE GENERATED WITHIN AIRCRAFT.

1. Receiver inherent background noise.
2. Interference from rotating machinery.
3. Interference from arcing and sparking of contacts, such as relays, poor ground connections, etc.
4. Ignition interference.
5. Interference from pulsed electronic devices such as radar transmitters.

TABLE II

DESIGN GUIDES SUGGESTED BY MIL-I-6181B

Interference free design—Interference minimization shall be considered in the basic design of all electronic and electrical equipment components, assemblies and systems. This design should be such that before means of suppression are applied, the minimum amount of radio interference is inherently generated and propagated. The application of radio interference reduction components that must be used, such as filtering, shielding, and bonding shall conform to good engineering practice, and, wherever possible, shall be an integral part of the system. Whenever additional suppression is necessary, the use of miniaturized suppression components is encouraged.

Component placement—Components shall be placed and circuitry arranged in order to result in a minimum of undesired coupling and in the use of a minimum of filter components.

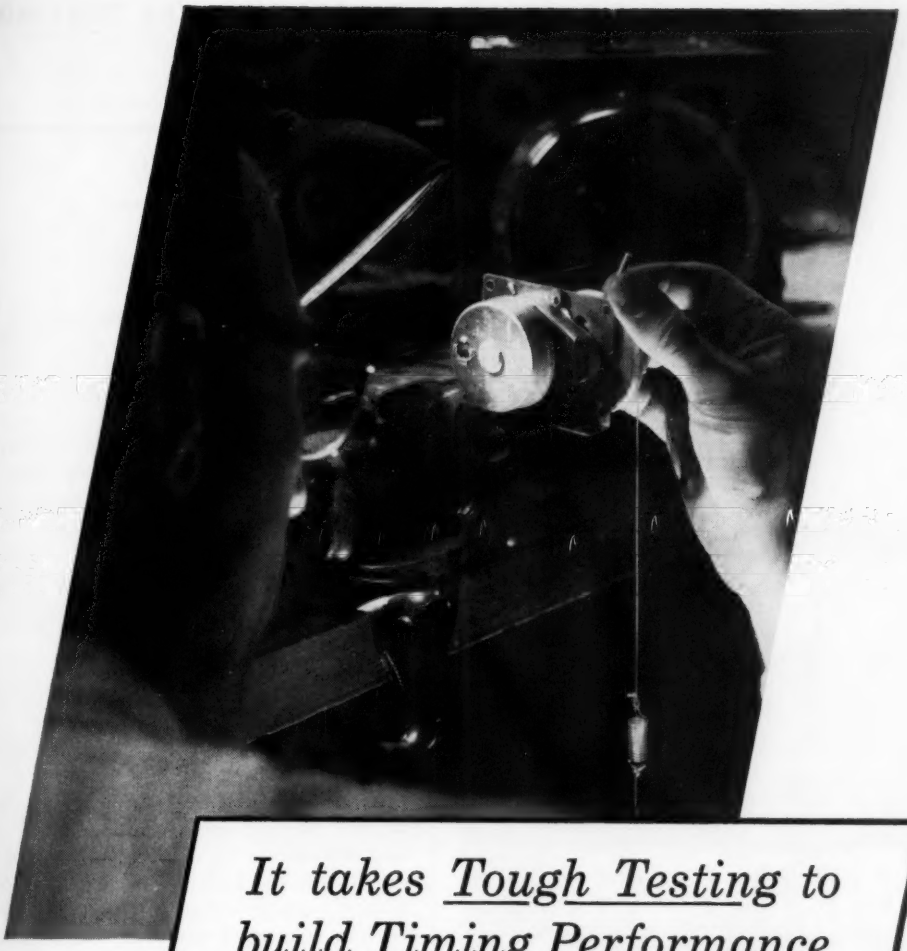
Line shielding—Whether a line shall be (a) shielded, or (b) filtered, shall depend upon which method results in the least weight and space penalty for the overall system. In general, however, it is preferred that interference reduction be accomplished inside the equipment units when such means give results equal to or better than the use of a shielded line. If shielding is used, it shall be prescribed as an installation requirement.

Case and mountings—Enclosing case construction, where applicable, should provide enduring continuity of electrical shielding and conducting paths to prevent leakage through discontinuities in the shield. Mating bearing surfaces of the case and mounting shall be free of all insulating finishes to enable the installing activity to accomplish bonding contact to basic structure. Such surfaces shall be covered with strippable tape or other protective coating to prevent corrosion prior to installation. For bonding purposes, this requirement shall take precedence over any conflicting requirements in finish specifications.

Shielding antenna lead-in—Equipments requiring antennas and not employing wave guides, shall be designed to utilize a shielded antenna lead-in.

Radio interference filters—Where additional interference suppression is required, after careful design in conformance with the foregoing, the suppression components should be installed inside the enclosing case of the interference source. Interference filter assemblies not hermetically sealed, shall employ only hermetically sealed capacitors, and shall be capable of withstanding all of the service operating conditions of the interference source. As a second choice, where space does not permit the installation of filters within the case of the interference source, they may be attached to the outside of the case of the interference source, provided that the wiring between the interference source and the filter is properly shielded and that the filter is permanently bonded thereto. Separately installed interference filters shall not be used unless specifically authorized by the detailed specification.

Susceptibility—The equipment shall be designed to minimize susceptibility to radio and audio interference from other equipment. Where applicable, the enclosing case construction should be designed not only to minimize radio interference propagation, but should also be designed to minimize interference from external sources. Where conducted radio or audio frequency interference on the power leads or any external leads might cause interference, the leads shall be isolated from other leads to avoid coupling, and where necessary shall have a line interference isolation filter at their entry into the enclosing case. Receiving antenna input and any other low-level signal circuits should preferably be of low impedance, or of balanced design and where applicable, with terminating connectors so that coaxial or special transmission lines can be used to insure an interference-free installation. Routing of receiving antenna input or any low-level signal circuit within the equipment should be so designed and installed that interference is not picked up from power or control leads due to circuit coupling. Antenna or low-level signal circuit return paths or ground paths should be so arranged that the interference will not occur due to common conductive paths with other circuits or with the enclosing case grounding path.



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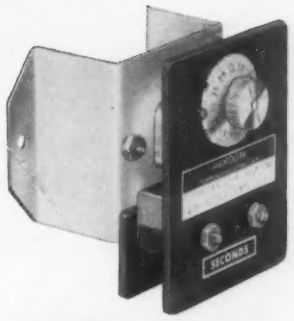
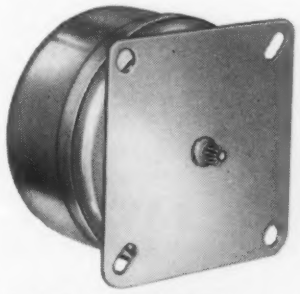


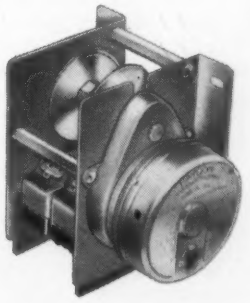
TIME DELAY TIMER

Provides time delay in ranges up to 9.5 minutes. Ideal for such applications as the protection of power tubes and/or operating preset operating cycles. Available in 120 or 240 volt, 50 or 60 cycle current.



400 CYCLE MOTOR

These split phase motors provide the military an accurate approach to timing control for military applications. Rotor speed is 3,000 RPM at 400 cycles, 115 volt normal. Two models are available — Heavy Duty with 18 gram millimeters torque at the rotor, and the Miniature with 5 gram millimeters at the rotor. These motors may be applied to Haydon gear trains if desired.



CYCLE TIMER

These units repeat a set cycle or sequence of operations as long as the motor is energized. Available in a wide choice of speeds, a broad range of timing intervals, and with a wide range of enclosed single pole, double throw switches for 120 and 240 volt operation, for 50 and 60 cycles.

CIRCLE 41 ON INQUIRY CARD

TABLE III

FACTORS TO CONSIDER IN SPECIFYING MAGNETIC SHIELDS

1. AC or DC fields or both.
2. Intensity of magnetic field to be attenuated, either in guass or in terms of voltage, developed by a pickup coil, introduced in the field.
3. Orientation of field or fields.
4. Desired attenuation either in decibels (with reference level) or voltage ratio.
5. Frequency range and characteristic of wave form.
6. Weight considerations.
7. Temperature range.
8. Environmental conditions to which items will be exposed.
9. Finish desired.
10. Other pertinent information.

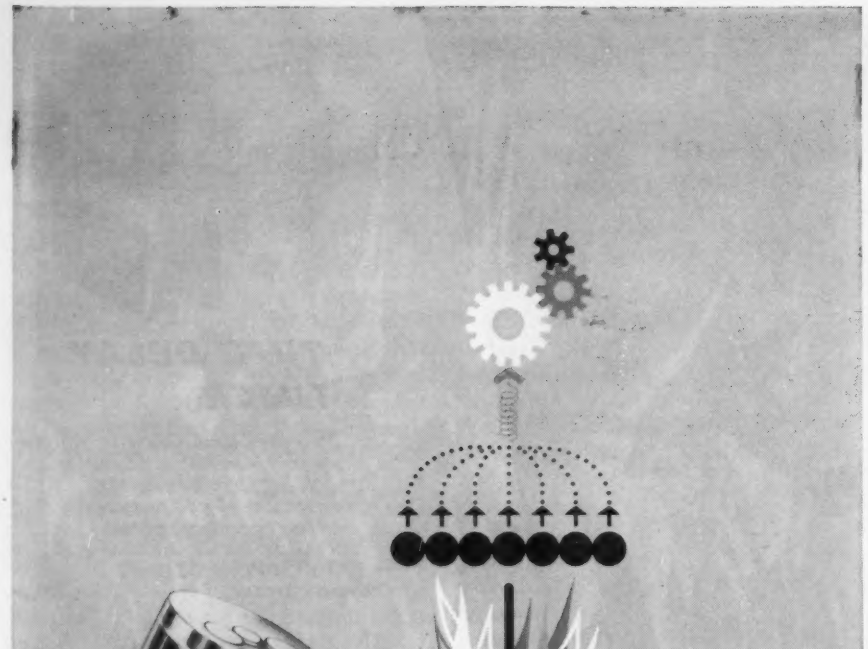
Stray capacitance coupling is controlled by use of suitable shielding and separation of leads. High voltage circuitry should have low capacitance to low voltage signal circuits. Suitable wiring arrangements help minimize this. Shielding should not be used indiscriminately, however, since the capacitance which it introduces may interfere with the operation of the circuitry. The circuit should be dealt with as if actual capacitances were inserted in the shielded lines, to ascertain the effects on performance.

Inductive coupling is due simply to the common mutual inductance between current-carrying conductors. It is minimized by separation of power and signal leads, the free use of twisted

TABLE IV

SPECIFICATIONS COMMONLY APPLIED IN ENVIRONMENTAL LABS

MIL-E-5272A	Aeronautical Equipment
MIL-T-5422C	Environmental Tests
MIL-E-5400A	Aircraft Electr. Equip.
MIL-T-945A	Test Equipment
MIL-C-5015C	AN Connectors
MIL-R-5757C	Relays
MIL-P-6064A	Packaging
AN-C-176-3	Control Panels
MIL-P-6906	Identification Plates
MIL-C-7974	Connectors and Cables
MIL-I-6051	Radio Interference
MIL-I-6181B	Radio Interference
MIL-E-8189A	Guided Missiles
MIL-R-10509B	Resistors
MIL-S-16892 (BuOrd)	Synchros 400 cycles
MIL-R-25018	Relays, Miniature
AF 41065	Environmental Tests
ANA Bulletin 405	Storage Life



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pairs, avoidance of large loops, such as might inadvertantly occur as a result of poor grounding practice, and the optimum orientation of sets of leads. Circuits that generate no inductive fields are similarly unsusceptible to pick-up from inductive fields. Inductive coupling is at its worst over short distances compared to the wave-length of the frequencies considered. Over longer distances radiation coupling becomes more significant. Shielding of inductive circuits may be accomplished by using high permeability shields. However, shielding of inductive circuits is not as simple as electrostatic (capacitance) shielding, and the advice of specialists should be sought. In simple cases, the use of totally inclosed high permeability cans provides adequate shielding. Magnetic Shield Division, Perfection Mica Company recommends consideration of the factors of Table III in specifying magnetic shields.

Electromagnetic radiation must be controlled at the sources of interference, since obviously the antenna of a receiver cannot be shielded. This is accomplished by preventing RF currents from flowing in power leads (by filtering), and by suitable electrostatic shielding.

CONDUCTING OF TESTS

The acceptable test procedures for military equipment requires that the general arrangement of equipment, inter connecting cable assemblies, and supporting structures stimulate actual installation conditions as closely as possible. Shielded leads or cables are used only where they are so used in actual practice except that shielded dummy antennas are used for receivers and transmitters.

To minimize the ambient interference level during testing, a shielded enclosure may be used. Such an enclosure should include a ground plate, preferably of copper, of sufficient area to serve as an adequate work space, with good closely spaced conducting bonds to the shielded frame. During test, bonding straps between pieces of equipment, and to ground are used as provided for by the design of the equipment.

Environmental Test Chambers

Environmental test chambers are used for the great majority of tests called for in military specifications. These include temperature, humidity, altitude, salt spray, sand and dust, and others. Kearfott Company lists the

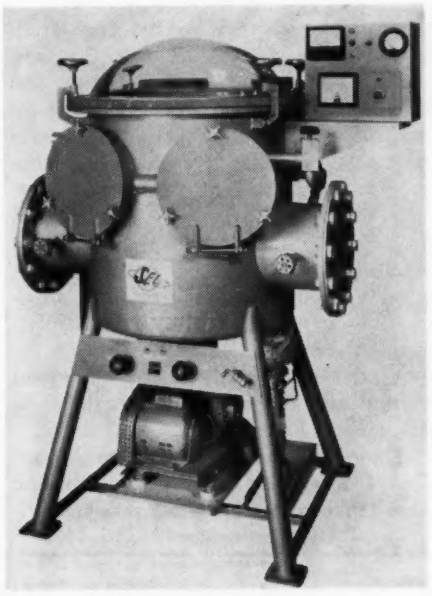


Fig 1 High altitude, extreme temperature test chamber featuring all-welded stainless steel construction

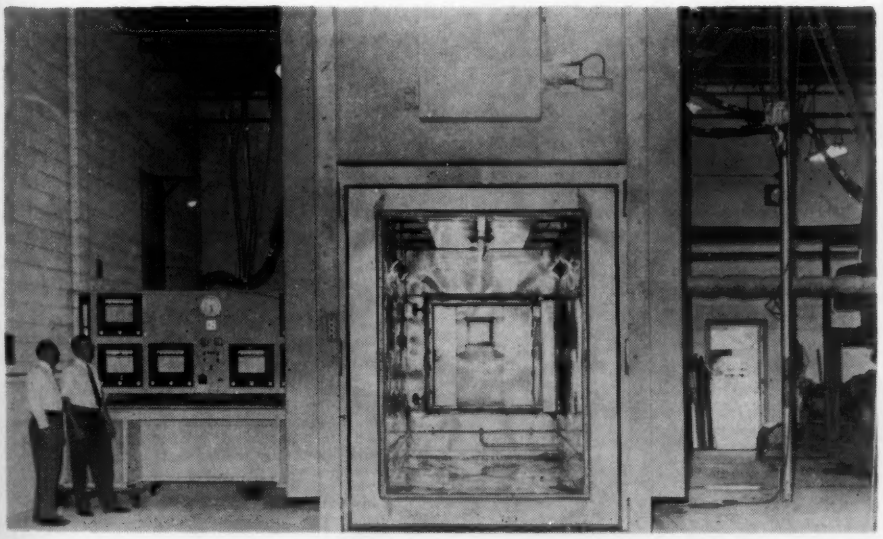
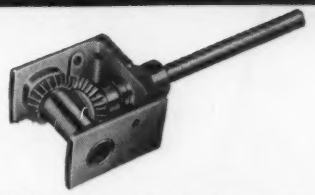


Fig 2 Dual compartment temperature-altitude chamber.

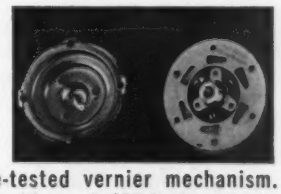
NATIONAL

PRECISION RIGHT ANGLE AND VERNIER DRIVES



Type PRAD: Right angle drive for remote operation of low torque units. Designed for continuous low-speed operation (loads up to 50″ ounces), and intermittent high speed operation (up to 500 RPM) with loads up to 100″ ounces. Less than 1½° backlash; drives and shafts of various lengths; various size output hubs; brass gears; stainless steel shafts, bushings and sleeves; die cast zinc housings.

Type RAD: Right angle drive. For ganging capacitors, potentiometers or other parts in heretofore inaccessible locations on chassis. Die cast zinc housing gears.



Type AN: Time-tested vernier mechanism. Designed for use with any 3/16″ National knobs and others. Drive ratio: 5 to 1; drive shafts: 3/16″, 1/4″ or to specifications; fully insulated output shaft coupling; output hub fits ¼″ shaft; readily adaptable to many types of drives.

Type AVD: Vernier mechanism. Similar to type AN (above) except that output-shaft is non-insulated. Dimensions: over-all diameter 2-9/16″, length 1-15/32″.

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COMPONENTS DIGEST

specifications of Table IV as the more common which must be met in its environmental laboratories. This list supplements the purely environmental specification listing previously given in Components Digest 4, Part I.

Today's tendency is to emphasize combined environments. Test chambers are now available to perform simultaneous temperature-altitude tests, temperature-humidity tests, temperature-vibration tests and temperature vibration-altitude tests. The design of these chambers is becoming more intricate as a result of extreme temperature ranges extending from −300F to +1000F in special cases, with altitude requirements ranging 400 miles. The necessity of combining vibration, temperature and altitude in a single chamber further emphasizes the specialized nature of these chambers.

"There is definitely a strong trend toward combined testing of missile components. It has been proved that many components which function satisfactorily in any one of the flight environments fail to function properly or even fail structurally when subjected to multiple environments", says Wyle Associates of California.

They are now being asked to do random (as well as sinusoidal) vibration simultaneous with acceleration, altitude, temperature, humidity, and explosive atmosphere-plus specimen function. Such combined testing has never before been accomplished, to their knowledge, and they are completing construction of two machines for conducting this complex type of testing.

Fig 3 For a 100 mile maximum simulated altitude, this walk-in chamber can attain 285,000 feet in 10 minutes.

Scientific Engineering Laboratory describes their Model 662 (Fig. 1) which simulates conditions to altitudes exceeding 100 miles. This has been achieved by matching vacuum pump equipment to precision welded chambers. The unit of Fig. 1 may include temperature control over the range of −190C to +400C in a programmed manner. As requirements are changed, master altitude chambers can be reconverted to incorporate new interior elements.

Conrad, Incorporated describes a vibration-temperature-altitude combined chamber covering the range of −100F to +500F. Design features call for the use of Teflon and Silicone gaskets on

TABLE V

SPECIFICATION OF ENVIRONMENTAL TEST CHAMBER

1. Description of application
2. Style of Cabinet. Top opening, front opening
3. Working space required
4. Temperature requirements
5. Required cooling time (range of temperature, minutes)
6. Required heating time (range of temperature, minutes)
7. Humidity requirements, lowest relative humidity, highest relative humidity, programming, temperature variations
8. Altitude requirements
9. Rate of change of altitude
10. Product load information, weight, material
11. Heat dissipation from product (during various cycles)
12. Ambient temperature of chamber location
13. Temperature control, type, indicating or non-indicating
14. Altitude controller, indicating and non-indicating programmer
15. Additional accessories
16. Pilot light for indication of operation of equipment
17. Percentage capacity control for the heating rate
18. Percentage capacity control for the cooling rate
19. Glass viewing window, size
20. Reach-in ports (size and location)
21. Interior lighting
22. Forced air circulator or liquid circulator
23. Conduits for cable and wire entrance, size, number and location
24. Size and number and type of terminals required
25. Shelves for interior of test space, number, material, fixed or adjustable.

(Percentage control is recommended for increasing the accuracy of temperature control for temperature testing systems and for improved control of systems with humidity control. This stops the overshooting or undershooting of test points at intermediate temperatures near ambient conditions where reduced capacity on both heating and cooling is necessary.)

the chamber doors, Silicone, Teflon, and Asbestos insulated wiring, and, where vibration equipment is incorporated within the chamber, silicone and fiberglass diaphrams to permit the vibration equipment itself to withstand the extreme temperatures. Typical performance characteristics may call for a temperature change from room temperature to −70F in 38 minutes, room temperature to +500F in 30 minutes, altitude from ambient pressure to 100,000 feet in 20 minutes. Altitudes to 150,000 feet are considered quite standard, and requests are common for altitudes 250,000 feet, and occasionally to altitudes of 500,000 feet.

Fig. 2 shows a Conrad walk-in dual compartment temperature-altitude chamber with a capacity of 1200 cubic feet. These larger chambers are becoming increasingly important for testing of complete systems, and major sections of missiles and aircraft. This chamber, covering the range from −120F to +650F and altitudes to 125,000 feet, has a partition in the center that converts the single chamber into 2 independent chambers when the separating door is closed. Altitude, heating, cooling and humidity can be simulated in either section or as one complete chamber. The chamber is capable of maintaining a temperature of −100F with a total of 40 kilowatts of internal dissipation from the equipment being tested. In purchasing or specifying an environmental test chamber, Conrad, Inc. suggests the application engineering data as summarized in Table V.

General Vacuum Corp. describes walk-in chambers simulating altitudes to 100 miles. Their Type 988 (Fig. 3) is 6 ft. x 6 ft. x 6 ft. and the pumping system is sized to reach 285,000 ft. altitude in ten minutes. The chamber includes automatic systems for recording and controlling altitude or a programmed climb and descent, feed through for power, instrumentation, gas and liquid sampling, locks for specimen introduction or removal.

Tenney Engineering, Inc. confirms that increased demand today is for nonstandard test chambers combining temperature, altitude and vibration. They indicate that chambers have been constructed with temperatures ranging from −120F to as high as 1000F to be used in conjunction with vibration exciters. Where vacuum is necessary in conjunction with temperature and vibration, the vibration/shaker is placed outside the chamber and connected with a push-rod through the wall to an auxiliary table. However, this type of arrangement is applicable for only low frequency tests to between 200 and 500 cycles/second. Where tests run into the kilocycle range, the shaker

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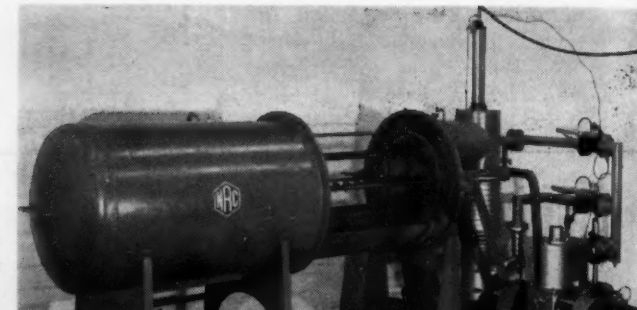


Fig 5 An inexpensive way of acquiring facilities for simulating altitudes up to 200 miles is to adapt one of the standard vacuum coaters which are available in sizes from 10″ in diameter x 12″ high to 66″ diameter x 60″ long, complete with necessary pumping systems, instrumentation, controls panels, and power feed-throughs. The National Research Corp. Model 3143 Vacuum Coater shown here has a chamber 42″ in diameter x 60″ and is especially handy for environmental test work because of the cantilevered shelf (whose normal function is to support the planetary jig which holds the parts to be coated).

proper is placed inside the chamber; the chamber is constructed to withstand the forces as well as to dissipate the heat generated. Shakers have been developed which can be placed inside the chamber to operate satisfactorily under the temperature conditions.

While no special problems are met in the construction of chambers to simulate altitudes up to 100,000 feet, those which can create the lower pressures associated with higher altitudes must be built according to the techniques used by manufacturers of high and ultra-high vacuum equipment. This involves careful choice of materials, precision fabrication and leak testing, special pumping systems, and indirect gauging techniques. Figures 4 and 5 show two chambers designed to simulate environments up to 200 miles altitude. Table VI presents National Research Corporation's rule-of-thumb specifications for chambers intended to simulate different altitudes.

Here are some of the factors NRC found increasingly important in the simulation of higher altitudes

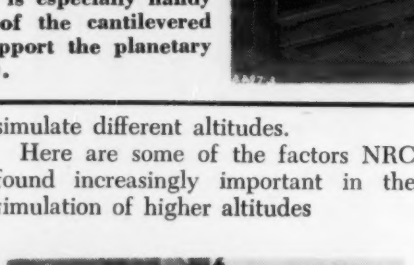


Fig 6 Chamber for temperature shock testing.

• Boyle's Law, which in effect states that the volume occupied by the same mass of gas varies inversely with its pressure. As a result, leaks and gas evolution which are not troublesome at high pressure become more significant as the pressure drops. For instance, if a can containing a liter of air at sea level is opened at 100,000 feet, its contents will occupy about 760 liters, and at 300,000 feet 7,600,000 liters.

• Outgassing, which is the evolution of gases or vapors under vacuum. Two effects must be considered. A surprisingly large number of materials, including some metals, cannot be used in a high vacuum system because their vapor pressures are so high that they would vaporize before the desired pressure could be reached. In addition, surface films of adsorbed air and vapors are liberated as the pressure drops. Water vapor is especially troublesome, as a single drop of water will occupy about 100,000 cubic feet at pressure equivalent to an altitude of 300,000 feet. To reduce the load on the pumping system the vacuum chamber should

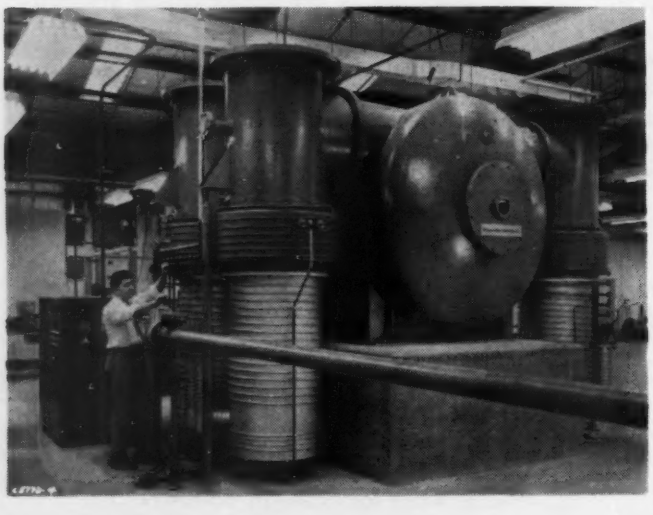


Fig 4 Pressures encountered at an altitude of 200 miles have been simulated in this 7′ diameter x 12′ high altitude test chamber installed by NRC Equipment Corp. at New Devices Labs of Thompson Ramo-Wooldridge, Cleveland, Ohio. Three optically baffled National Research Corporation H-32-P 32″ diffusion pumps provide the very high pumping capacity needed to remove large quantities of gases such as might be evolved in testing advanced propulsion devices.

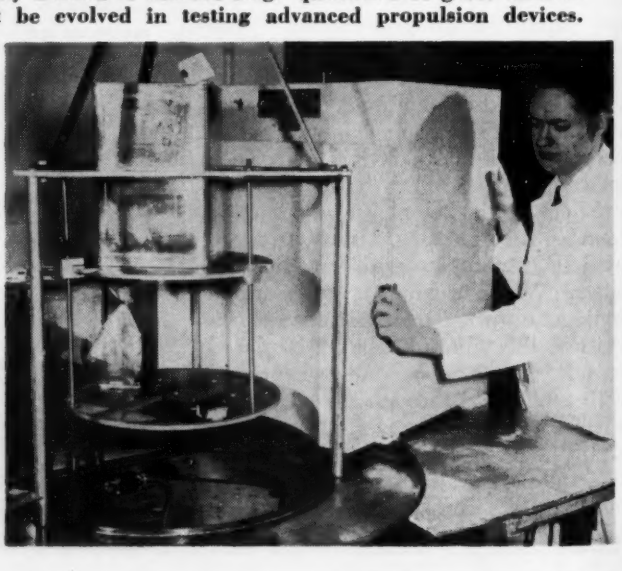


Fig 7 Technician removing plastic and elastometer test specimens from Hudson Bay Company's irradiation chamber. The front face of this specially designed radiation resistant chamber was made concave to fit around the Cobalt 60 source can. This chamber, capable of maintaining a temperature of 200C, permits the investigation of the effects of high temperature and nuclear radiation on test specimens.

have a minimum surface area, so as to limit the amount of adsorbed gases. This rules out the use inside the chamber of porous material such as thermal insulation, and often calls for grinding welds and polishing the chamber walls.

• Low Pressure Gas Characteristics. At low pressures gas molecules are so spread out that special devices, such as diffusion pumps, must be used to concentrate them to a level where conventional pumps can remove them. The force they exert is so slight that normal pressure measuring instruments, such as diaphragm gauges or manometers, cannot be used. To achieve efficient pump down times, manifolding must be as short as possible and offer the largest unobstructed area possible.

Tenney forecasts altitude requirements in the range of 10^{-6} 10^{-7} mm Hg, to be made available shortly in combination temperature chambers. They also point out that requests have been received for acceleration, radiation, and particle impact tests to be performed in conjunction with temperature and altitude.

Simulation of outer space conditions has been further described by Missimers, Inc. A recently developed chamber covers the range from −300 to +1000F in a single self-contained unit. This chamber is being used in conjunction with a universal testing machine to perform tension, compression, flexural and fatigue tests on missile components at temperatures such as might be encountered in outer space.

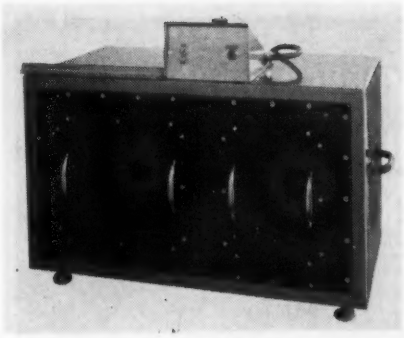


Fig 8 Miniature Test Chamber by Wyle Associates.

The same chamber could be used with a vibration shaker for tests at extreme temperature.

A second chamber recently developed by Missimers is a 14 cubic foot unit designed for temperature shock testing. Temperature can be reduced from +160 to −65F in less than 3 minutes or can be heated from −65F to +160F in less than 3 minutes. Temperature control tolerance is ±2 degres after stabilization at any temperature. Fig. 6 shows the construction of this test chamber.

Hudson Bay Company has developed cabinets for investigation of high temperature nuclear radiation effects, on materials and components for operation in conjunction with reactors, for military use, or for space environments. The cabinets use refrigeration cycles designed for radiation testing new materials. Insulation, and wiring had to be appraised from the viewpoint of their possible radiation. The finished test cabinet, Fig. 7 includes facilities for environmental tensile testing with a range of temperatures from −65F to +650F. They operate with a compound type of condensing system; combination water air-cooled condensers are used. The generating equipment is surrounded by a concrete wall and is operated remotely from the test chamber for safety reasons. Test cabinet of the figure is a 1½ foot cube radiation oven for high temperature testing. Specimens may be stored in its concave door as well as in the main area. Its concave shape permits all tests specimens to to be an equal distance from the cylindrical cobalt source and thus be assured of a uniform radiation dose. The chamber maintains a constant temperature for accurate radiation testing on rubber, plastics, elastomers, as well as other materials.

Environment Equipment Corporation of Brooklyn, N. Y. markets a series of chambers and walk-in rooms that run the gamut of all types of single or multiple combination tests.

In spite of all the emphasis on large test chambers, the component manufacturer requires smaller versions to evaluate components such as resistors, small electric motors, relays, etc. While the chamber must be sufficiently large to provide good temperature stability and control, excessive size only adds to the cost of purchase and operation. The Wyle miniature test chamber, Fig.

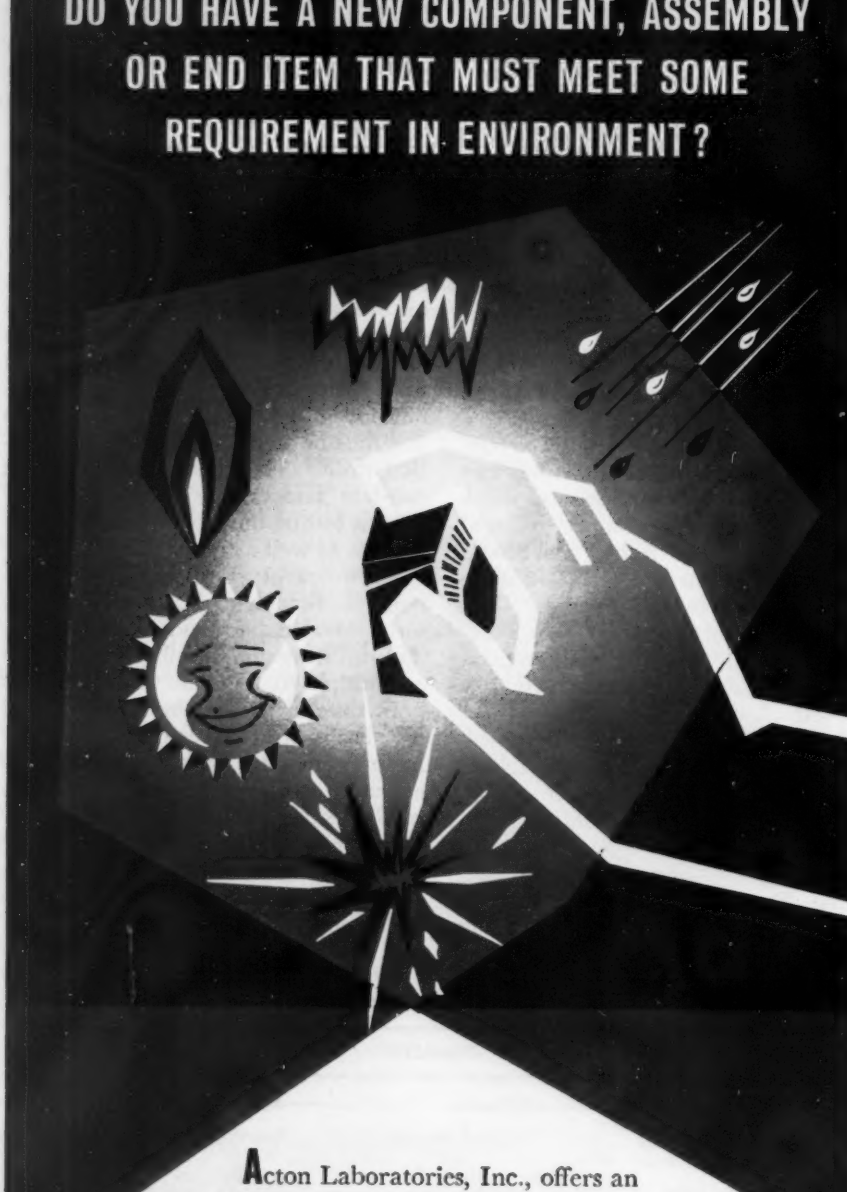
TABLE VI RULE-OF-THUMB SPECIFICATIONS FOR ALTITUDE CHAMBERS

HEIGHT	20 miles	60 miles	200 miles	Above 200 miles
APPROXIMATE PRESSURE[1]	1 mm Hg	1 x 10^{-4} mm Hg	1 x 10^{-7} mm Hg.	Less than 1 x 10^{-7} mm Hg.
CHAMBER CONSTRUCTION				
Chamber Material	Carbon Steel	Carbon Steel	Stainless Steel	Stainless Steel or Glass
Welds	Standard	Single Weld	X-Ray Quality	X-Ray Quality
Cleaning & Finishing	None	Sandblast	Grind and Polish	Grind and Polish
Leak Test Method	Soap Bubble	Mass Spectrometer Leak Detector	Mass Spectrometer Leak Detector	Mass Spectrometer Leak Detector
Acceptable Leak Rate	(As measured by above test)	1 x 10^{-6} std. cc./sec.	1 x 10^{-9} std. cc./sec.	Less than 1 x 10^{-9} std. cc./sec.
Gasket Material	Standard	Low Vapor Pressure Organic[2]	Metal[3]	Metal[3]
Thermal Insulation	Inside Chamber	Outside Chamber or Heat Shields	Outside Chamber or Heat Shields	Outside Chamber or Heat Shields
Rate of Rise[4]	Not Significant	10 microns/hr.	0.5 microns/hr.	0.1 microns/hr.
Provision for Bake-Out[5]	No	No	Preferable	Yes
PUMPING SYSTEM				
Type	Common Mechanical or Steam Jet	Diffusion	Diffusion with Liquid N_2 Baffle	Diffusion, Liquid N_2 Baffle, and Exotic[10]
Manifold Design Important	No	Yes	Yes	Yes
GAUGING				
Direct Effect	Diaphragm or Manometer	No	No	No
Indirect Effect	Alphatron[6] Ionization	Hot-Wire[7], Maclead, Alphatron[6], Std. Ion or Phillips	Standard Ionization or Phillips	Bayard-Alpert, Nottingham[8], or Redhead[9]

NOTES

1. Atmospheric pressure = 760 mm Hg/760,000 microns Hg.
2. Such as neoprene, silicone rubber, or Teflon®.
3. Such as aluminum or copper O rings, or liquid metal seals.
4. Measured from 1 micron, with pumps valved off.
5. Used to accelerate removal of adsorbed gases.
6. Registered trade name of NRC Equipment Corporation, Newton, Mass.
7. Thermocouple or Pirani-type, ordinarily limited to pressures from 1000 to 1 micron.
8. Improved Bayard-Alpert, now available from NRC Equipment Corporation.
9. Measures to 1 x 10^{-14} mm Hg., available soon from NRC Equipment Corporation.
10. Includes Getter-Ion Pumping, Ionization pumping, and cryopumping.

DO YOU HAVE A NEW COMPONENT, ASSEMBLY OR END ITEM THAT MUST MEET SOME REQUIREMENT IN ENVIRONMENT?



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8, is suitable for this type application. Delta Design Engineers, Inc. of La Jolla, Cal. make a rack mounted chamber with a range of −100F to +500F; test volume is 10″ x 7″ x 7″. The unit occupies 10½″ of height in a standard 19″ rack. Such units are ideal for testing subassemblies and components in a minimum of bench space.

Vibration and Acoustic Noise Testing

This important subject has already been treated in some detail in the initial coverage of Components Digest 4. In this presentation we will provide additional information received from test equipment manufacturers in answer to our questionnaire.

David Ehrenpreis, Consulting Engineer, describes a vibration excitation table designed to vibrate up to 10,000

TABLE VII VIBRATION TEST FAILURES

AIR-BORNE GYROSCOPE:
- Wire failure at ends.
- Brinnelling of bearings.
- Gyro dumping.
- Gyro drift rate increase.

AIR-BORNE RADAR:
- Wire failures at ends.
- Bracket failure.
- Tube failure.
- Radar not locking on target.

AIRBORNE GUN TURRET:
- Gun-fire circle too large.
- Gun pointing down.
- Radar wire failures.
- Gear train chatter.
- Bearing brinnelling.

HELICOPTER-BORNE COMPUTER:
- Wire failures.
- Isolator failures.

AIRBORNE TRAVELING WAVE TUBES:
- Excess deflection helix.
- Excess deflection rods.
- Excess deflection gun-end.
- Excess deflection heater.
- Failure rods.
- Failure heater support.
- Failure springs.

AIRBORNE REFERENCE UNIT:
- Brinnell bearings.
- Crack gimbal castings.
- Failure brackets.
- Failure tubes.
- Failure wire at ends.
- Chatter relays.

MISSILE-BORNE PRESSURE MONITOR:
- Incorrect readings.
- Failure bellows.
- Failure springs.

MISSILE-BORNE COMPUTER:
- Failure card supports.
- Failure wires.
- Failure brackets.
- Failure lugs.

MISSILE-BORNE INERITAL PLATFORM:
- Failure wires.
- Crack gimbal ring.
- Crack gears.
- Errors in reference.

cps at 10g, with a total dynamic force of 21,000 lbs. He further mentions tables for vibration to 500 cycles with a total dynamic force of 2,000,000 lbs. Other special units include random vibration excitation tables and random shock excitation tables for high-speed ICBM applications. Mr. Ehrenpreis reports the use of high-speed digital computers to predict the effects of design modifications on electronic equipment to improve vibration characteristics. Table VII lists vibration failures and symptoms in military equipment which Mr. Ehrenpreis has encountered. Of special severity are a 48" drop test on a concrete pavement, on each axis, a sustained resonance dwell of 30 g on each axis, and sweep vibration to 3000 cycles 30 g.

Rototest Laboratories describes high intensity acoustical noise facility, and suggests that noise test specifications include the maximum physical size and package type of the object to be tested, the sound pressure level required on the basis of overall energy in the seven octave bands (75 cps to 10,000 cps), and the frequency spectrum pattern. Recent failures under white acoustic noise include:

Noise peaks in potentiometer, loss of wiper contact. Failure occurred at 132 db level. Damaging frequencies were confined to two octaves, 300-600 cps, and 600-1200 cps, more specifically to two-cycle bands at 340 and 68 cps. The narrow band-widths are characteristic of many mechanical resonances. Correlation with a sine-wave vibration test was poor.

Closed circuit TV camera: a vibration isolated camera was placed in test chamber with sound pressure of 150 db, random noise from 75 cps to 10 kc, with equal levels in all octaves. Snow and streaking and, 20 minutes later, intermittent performance occurred. Loose screws, shorting by a section of bare wire, and microphonics in the Vidicon tube were to blame. Relays at 145 db sound pressure exhibited complex behaviour including arcing and dynamic contact resistance, with the moving contact appearing to "float" between its two portions for relatively long periods.

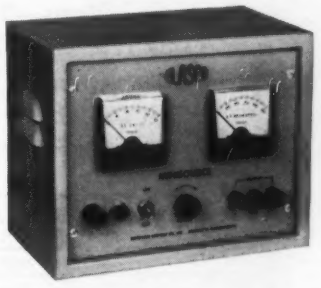
A synchro exhibited spikes in its null voltage due to brush lifting at 142 db. In vibration testing, brush lifting was observed at 10 g's and 205 cps.

A 7 inch diameter mirror, completely isolated against vibration, vibrated badly as sound pressure level increased from 135 db to 150 db and shattered in 40 seconds at the higher level.

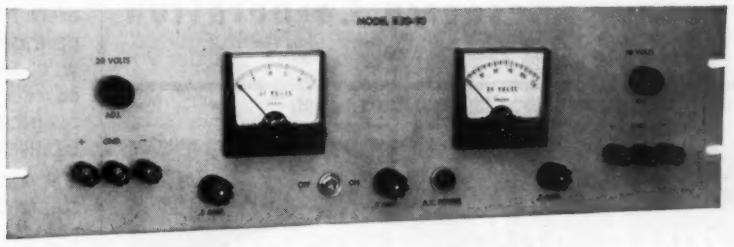
Crystal accelerometers exhibited substantial output noise at levels from 135 db to 150 db. Output readings were estimated to be low by about 10%.

power supplies

Transistorized • Transformer Cased
3 5/16 x 3 7/8 x 4 1/2 • Basic Price: $64 to $127



Lab Model ○ Basic Price plus $60



Rack Mounted • Basic Price plus $50

MINISOURCE Power Supplies

100% SERVICEABLE

No Potting
Printed Circuit Design
Accessible Components

Full Wave Bridge
Flexible E&I Ratings
Standard units from 5 to 50 volts at currents from 50 to 500 ma or units designed and built to customer specifications.

INPUT: 105—125 V AC
REGULATION: better than 0.5%
RIPPLE: better than 0.5%
OUTPUT IMPEDANCE: less than 0.25 ohms, DC—100 kc
POLARITY: grounded or floating operation
TEMPERATURE: compensated from —10 to 55C
PRICE RANGE: Indicated below each unit

Send for complete catalogue

Elasco

ELECTRONIC ASSEMBLY CO., INC.
Five Prescott Street, Roxbury 19, Mass.
Highlands 2-1600

CIRCLE 47 ON INQUIRY CARD

now available

OPTISYN

Incremental Digital Pickoff With New Optical Principle

Model PH VII-1 shown with integral transistor amplifier

Low Torque—0.05 oz-in
Fast Slew Rate—3000 rpm
Small Size—2.3 dia x 15/16 length
Inertia—52 gm-cm² • Weight—7 oz
High Reliability — no brushes

MODEL	RESOLUTION
PH VII	2^{11}, 2^{10}, 2^{9}
PH VIII	2^{13}, 2^{12} (Special)
PH VI	one part in 2000, 1000 or 500
PH V	one part in 400, 200 or 100

Eva'uation units (PH VII) available for 30 day delivery: $735.00

Dynamics Research Corporation

44 Winn Street Woburn, Mass.

CIRCLE NO. 48 ON INQUIRY CARD

push-pull

CONTROLS

Compression & Tension Type

Aircraft cable is strung with spherical steel shells in a rigid or flexible housing sealed with "O" rings. 3" standard bend radius. ¾" minimum bend radius.

Three Types:

1. ***Light Duty***—Compression Ult. Load 1250 lbs.; Ult. tension 960 lbs.
2. ***Heavy Duty***—Compression Ult. Load 1650 lbs.; Ult. tension 960 lbs.
3. ***Extra Heavy Duty***—Compression Ult. Load 3050 lbs.; Ult. tension 3900 lbs.

Positive remote controls for actuating mechanical, hydraulic or other devices. Eliminate bell cranks, pulleys, and dual cables. U.S. Patent No. 2441719. All world rights reserved. Send for ENGINEERING MANUAL giving complete specifications covering materials, finishes, capacities. Please address Dept. EMD-PP-59.

SOUTHWEST PRODUCTS CO.
1705 SO. MOUNTAIN AVE., MONROVIA, CALIFORNIA

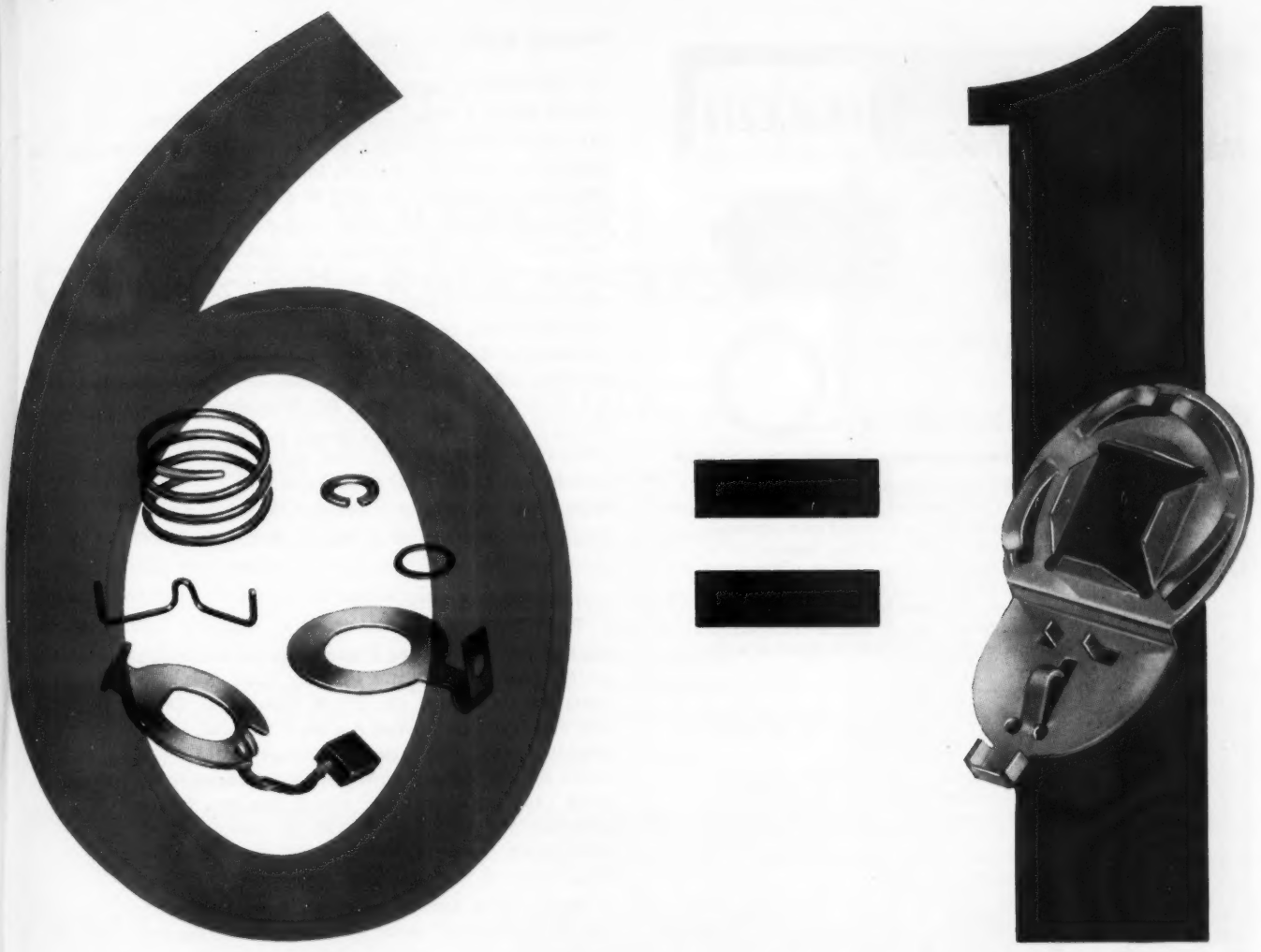
CIRCLE NO. 49 ON INQUIRY CARD

Buyers' Guide For Environmental Equipment And Laboratories

EQUIPMENT MANUFACTURERS

ACE ENGRG. & MACHINE CO., Tomlinson Rd., Huntingdon Valley, Pa.
AIRECO, INC., 2323 Second Ave., Schenectady, N. Y.
ALPHA ELECTRIC REFRIG. CO., 1115 E. 7 Mile Rd., Detroit, Mich.
ALTEC LANSING CORP., 1515 So. Manchester Ave., Anaheim, Cal.
AMERICAN INSTR. CO., 8030 Georgia Ave., Silver Spring, Md.
AMER. MACHINE & FOUNDRY CO., 1101 No. Royal St., Alexandria, Va.
AMERICAN RESCH. CORP., Route 6, Farmington, Conn.
ATLAS PREC. PRODS. CO., 3801 Castor Ave., Phila., Pa.
ATMOSPHERE CONTROL CO., INC., 5315 Chester Ave., Phila., Pa.
AVCO, MFG. CO., 201 Lowell St., Wilmington, Mass.
B & K INSTR., INC., 13 W. Hubbard, Chicago, Ill.
B T U ENGRG. CORP., Bear Hill Rd., Waltham, Mass.
BARRY CONTROLS, 700 Pleasant St., Watertown, Mass.
BEACH-RUSS CO., 50 Church St., N. Y., N. Y.
BECKMAN/HELIPOT, 2500 Fullerton Rd., Fullerton, Cal.
BEMCO, INC., Vanowen St., No. Hollywood, Cal.
BENSON-LEHNER CORP., 11930 Olympic B'vd., Los Angeles, Cal.
BLUE M ELECTRIC CO., 138th & Chatham, Blue Island, Ill.
BOWSER, INC., Tech. Refrig. Div., Eagle St., Terryville, Conn.
BUD RADIO, INC., 2118 E. 55th St., Cleveland, Ohio
CINCINNATI SUB-ZERO PRODS., 3932 Reading, Cincinnati, Ohio
G. L. COLLINS, 2820 E. Hullett St., Long Beach, Cal.
CONRAD, INC., 141 Jefferson St., Holland, Michigan
CONSOLIDATED ELECTRODYNAMICS CORP., Pasadena, Cal.
DAYSTROM-PACIFIC, 9320 Lincoln Blvd., Los Angeles, Cal.
DEAN PRODUCTS, INC., 1042 Dean St., Brooklyn, N. Y.
DELTA DESIGN ENGRGS., INC., 4526 Donald Ave., San Diego, Cal.
DEVELOPMENT ENGRG. CO., INC., 9 Cross St., Norwalk, Conn.
W. C. DILLON & CO., 14620 Keswick St., Van Nuys, Cal.
Dit-MCO, INC., Electr. Div., 911 Broadway, Kansas City, Mo.
DONNOR SCIENTIFIC CO., 888 Galindo St., Concord, Cal.
D. EHRENPREIS, Consult.-Des. Shock, Vibr. Equip., 14 W. 19th N. Y., N. Y.
ELECTRIC BOAT DIV., Gen. Dynam., Eastern Pt. Rd., Groton, Conn.
ELECTRIC HOTPACK CO., INC., 5074 Cottman Ave., Phila., Pa.
EMERSON & CUMING, INC., 869 Washington St., Canton, Mass.
ENDEVCO CORP., 161 E. California St., Pasadena, Cal.
ENVIRONMENTAL EQUIP. CORP., 371 Linden St., Brooklyn, N.Y.
FLIGHT REFUELING, INC., Friendship Airpt., PO 1701, Balt., Md.
GAERTNER SCIENTIFIC CORP., 1255 Wrightwood Ave., Chicago, Ill.
GENISCO, INC., 2233 Federal Ave., Los Angeles, Cal.
GENERAL VACUUM CORP., 400 Border St., East Boston, Mass.
GIANNINI RESEARCH LAB., 18400 S. Main St., Santa Ana, Cal.
GULTON INDUSTRIES, INC., 212 Durham Ave., Metuchen, N.J.
HARRIS REFRIGERATOR CO., 308 Riber St., Cambridge, Mass.
HIGH VACUUM EQUIP. CORP., 2 Churchill Rd., Hingham, Mass.
HUDSON BAY CO., Div. Labline, Inc., W. Grand Ave., Chicago, Ill.
INTERNAT'L. RADIANT CORP., 111 New York Ave., Westbury, N.Y.
KEARFOTT CO., 253 N. Vinedo Ave., Pasadena, Cal.
KINNEY MFG., Div. N.Y. Air Brake, Washington St., Boston, Mass.
L A B Corp., Skaneateles, N.Y.
LING-CALIDYNE, 9937 W. Jefferson Blvd., Culver City, Cal.
LITTON INDUSTRIES, 41 & Sheridan Rd., Beverly Hills, Cal.
LYCOMING, Div. Avco, 550 So. Main St., Stratford, Conn.
McGREGOR MFG. CORP., 2785 E. Maple, Birmingham, Michigan
McMILLAN INDUSTRIAL CORP., Brownville Ave., Ipswich, Mass.
MB MFG. CO., Div. Textron, Inc., P O Box 1825, New Haven, Conn.
P. R. MALLORY & CO., 1302 E. Washington, Indianapolis, Indiana
MARQUARDT AIRCRAFT CO., 16555 Saticoy St., Van Nuys, Cal.
MIDWESTERN INSTRUMENT, 2420 N. Lake Ave., Tulsa, Oklahoma
L. C. MILLER CO., 5005 E. Slavson Ave., Los Angeles, Cal.
MODERN LABORATORY EQUIP. CO., 1811 1st Ave., N.Y., N.Y.
MURPHY & MILLER, INC., 606 W. Taylor St., Chicago, Ill.
N.J. DYNAMIC TESTING LABS., Box 32, Livingston, N.J.
NRC EQUIPMENT CORP., Charlemont St., Newton, Mass.
NON-LINEAR SYSTEMS, DelMar Airport, Del Mar, Cal.

Continued



with re-design 'rithmetic

One flat spring now does the work previously required of the six parts shown—and greatly simplifies assembly, too. This single multi-purpose spring (a) holds a carbon brush in a rheostat, (b) applies pressure on the wire windings, (c) provides friction detent action, (d) acts as a retainer on the rotating shaft.

How did this come about? The maker of the rheostat undertook a complete redesign analysis, called in an A.S.C. Spring Engineer when it concerned the spring.

Early consultation with A.S.C. springmakers in new or redesign projects gives greater range to plans, safeguards against high production costs. Our booklet, "Designing Springs for Performance," may help you. Write for your copy.

5902

Associated Spring Corporation

General Offices: Bristol, Connecticut

Wallace Barnes Division, Bristol, Conn. and Syracuse, N. Y.
B-G-R Division, Plymouth and Ann Arbor, Mich.
Gibson Division, Chicago 14, Ill.
Milwaukee Division, Milwaukee, Wis.
Raymond Manufacturing Division, Corry, Penna.
Ohio Division, Dayton, Ohio
F. N. Manross and Sons Division, Bristol, Conn.
San Francisco Sales Office, Saratoga, Calif.
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Cleveland Sales Office, Cleveland, Ohio
Dunbar Brothers Division, Bristol, Conn.
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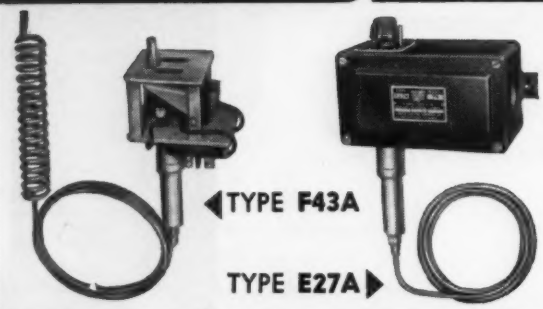
Canadian Subsidiary: Wallace Barnes Co., Ltd., Hamilton, Ont. and Montreal, Que. Puerto Rican Subsidiary: Associated Spring of Puerto Rico, Inc., Carolina, P.R.

CIRCLE 50 ON INQUIRY CARD

Dual Switch
REMOTE BULB
TEMPERATURE CONTROLS
F43A | E27A



The F43A and E27A are functionally similar units that are offered by UNITED ELECTRIC for applications where it is desirable to control two separate circuits at different temperatures by means of a single temperature control. The major differences between the two units are that the F43A is an uncalibrated, wide range, skeleton unit while the E27A is calibrated, has a narrow range, and is enclosed. If desired, the E27A can be modified to have a wide range.

Temperature Ranges . . .	F43A — up to maximum limits of −150° to +150°F., 70° to 370°F.. or 100° to 650°F. E27A — 100° or 200°F. spans between −150° and +650°F. limits.
On-Off Differential	Approximately 1.0°F. or 2.0°F. depending upon the model.
Switch Ratings	Up to 15 amps. at 115 or 230 volts A.C. 20 amps. A.C. or D.C. switches also available.
Switch Types	N.O., N.C., or Double Throw — no neutral position.
Adjustments.	F43A — slotted range adjustment screw on top, uncalibrated settings. E27A — external knob and pointer, calibrated settings. In each unit, switch may be adjusted individually to provide for approximately 15°F. max. span between switch settings. Span remains constant over entire range.
Electrical Connections . .	Via attached terminal blocks.
Capillary Tube Length . .	6-foot standard length. Other lengths available.
Mounting	F43A — via tapped holes in top plate. E27A — via mounting ears or tapped holes.

UNITED ELECTRIC *manufactures a complete line of temperature, pressure and vacuum controls. For special applications, standard units may be modified, or custom-built units may be provided. For additional data on remote type temperature controls, including types F43A and E27A, request* Section 200 *of our* new *catalog.*

U.E. United Electric Controls
COMPANY
SCHOOL STREET, WATERTOWN, MASS

CIRCLE NO. 51 ON INQUIRY CARD

Buyers' Guide *continued*

NUCLEAR CORP. of AMERICA, 33-61 Crescent St., L.I. City, N.Y.
OZONE RESCH. & EQUIP. CORP., North 40th Ave., Phoenix, Ariz.
PASTUCHIN AVIATION CORP., 5651 W. Century Blvd., Los Angeles, Cal.
PERFECTION MICA CO., Magnetic Shield Div., Chicago, Ill.
PRECISION SCIENTIFIC CO., 3737 W. Cortland, Chicago, Ill.
RHEEM ELECTR., Electr. Div., 7777 Industry Ave., Rivera, Cal.
THE RUCKER CO., 4700 San Pablo Ave., Oakland, Cal.
SCHAEVITZ MACHINE WKS., Box 505, Camden, N.J.
SCIENTIFIC ENGRG. LAB., 2229 McGee, Berkeley, Cal.
SHIELDING, INC., 68 N. Reade Ave., Riverton, N.J.
STANDARD CABINET CO., 60 Washington Ave., Carlstadt, N.J.
STATHAM LABS., INC., 12401 W. Olympic Blvd., Los Angeles, Cal.
F. J. STOKES CORP., 5500 Tabor Rd., Philadelphia, Pa.
TEMPO INSTRUMENT, 240 Old Country Rd., Hicksville, N.Y.
TENNEY ENGINEERING, INC., 1090 Springfield Rd., Union, N.J.
THERMOSEAL GLASS CORP., Camden, N.J.
TROP-ARTIC, INC., 627 So. Mulberrt St., Muncie, Indiana
U. S. PLYWOOD CORP.. 55 W. 44th St., N.Y., N.Y.

TESTING LABORATORIES

ABRAMS INST. CO., 600-62 E. Shiawassee, Lansing, Michigan
ACTON LABORATORIES, 533 Main St., Acton, Mass.
AERO RESEARCH INSTR. CO., 315 N. Aberdeen St., Chicago, Ill.
AEROHM CORP., Div. Waters, Post Road, Wayland, Mass.
AEROTEST LABS, 129-11 18th Ave., College Pt., N.Y.
AMER. ELECTRO METAL, 320 Yonkers Ave., Yonkers, N.Y.
AMER. LABS, Div. Amer. Electr., 1536 E. Rose Ave., Fullerton, Cal.
APPLIED RESCH. LABS, 3717 Park Pl., Glendale, Cal.
ASSOCIATED TESTING LABS, 127 Clinton Rd., Caldwell, N.J.
AVCO MFG. CO., 201 Lowell Rd., Wilmington, Mass.
BJ ELECTRONICS, 3300 Newport Blvd., Santa Ana, Cal.
BILL JACK SCIENTIFIC INSTR., So. Cedros St., Solana Beach, Cal.
BOWSER-MORNER TESTING LABS, Bruen & Scott St., Dayton, Ohio
THE BUDD CO., 2450 Hunting Park Ave., Philadelphia, Pa.
DALE, PRODUCTS, INC., 1318 28th Ave., Columbus, Nebraska
DeMORNAY-BONARDI, 780 So. Arroyo Pkwy., Pasadena, Cal.
Dit-MCO, INC., Electr. Div., 911 Broadway, Kansas City, Mo.
T. A. EDISON INDUSTRIES, Roseland, N.J.
ELECTRICAL TESTING LABS, INC., 2 East End Ave., N.Y., N.Y.
ELECTRONIC ENGRG. CO. of CAL., E. Chestnut Ave., Santa Ana, Cal.
ELLISON DRAFT CAGE CO., 548 W. Monroe St., Chicago, Ill.
FLEXONICS CORP., 1302 So. Third St., Maywood, Ill.
GENERAL TESTING LABS, INC., 59 Washington Ave., Carlstadt, N.J.
GREER HYDRAULICS, INC., N.Y. Internat'l. Airpt., Jamaica, N.Y.
HALLICRAFTERS CO., 4401 W. Fifth Ave., Chicago, Ill.
MAGNAFLUX CORP., 7300 W. Lawrence Ave., Chicago, Ill.
MISSIMERS, INC., San Fernando Rd., Glendale, Cal.
N.Y. TESTING LABS, INC., 47 West St., N.Y., N.Y.
OZONE RESCH. & EQUIP. CORP., No. 40th Ave., Phoenix, Arizona
PARAMETERS, INC., 195 Herricks Rd., New Hyde Pk., N.Y.
ROTOTEST LABS, INC., 2803 Los Flores Blvd., Lynwood, Cal.
RUE PRODUCTS, Electronet Div., 1628 Venice, Venice, Cal.
SERVO CORP. of AMER., 2020 Jericho Tpke., New Hyde Pk., N.Y.
SERVOMECHANISMS, INC., 12500 Aviation Blvd., Hawthorne, Cal.
F. D. SNELL, INC., 29 W. 15th St., N.Y., N.Y.
SOUTHWEST PRODS., INC., Route 4-Box 90, San Antonio, Texas
P. A. STURTEVANT CO., Addison, Illinois
SUN ELECTRIC CORP., Harlem-Avondale, Chicago, Ill.
U.S. TESTING CO., INC., 1415 Park Ave., Hoboken, N.J.
UNITED TESTING LABS, 1200 S. Marengo, Pasadena, Cal.
WEATHERHEAD CO., 300 E. 131 St., Cleveland, Ohio
WEBCOR, INC., 5610 W. Bloomingdale, Chicago, Ill.
WEBER TESTING LABS, Div. Weber Instr., Schaefer St., Detroit, Mich.
WYLE LABS, 124 Maryland St., El Segundo, Cal.

DIGITAL VOLTMETERS OHMMETERS, RATIOMETERS

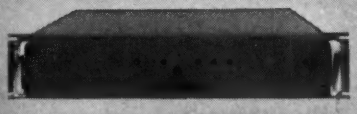
and Allied Products

Technological advance requires automatic high-accuracy measurements that only digital voltmeters can make. Customers in advanced fields find that NLS digital voltmeters last up to 5 and 10 times longer, a benefit from the producer who originated the digital voltmeter and who has the greatest research and development experience. Some applications are: missile checkout, computers, reliability testing, process monitoring, quality control, and general laboratory use. NLS features are unique because they were designed for application and not just for competition. Features of NLS meters include: *complete* transistorization, mercury relay digitizers rated at 3 billion readings, plug-in oil-immersed stepping switches, "no needless nines" digital logic for high speed and long life. Write today for complete data on AC-DC digital meters and accessories.

Prices and specifications subject to change without notice; prices (quoted f.o.b. Del Mar) slightly higher in Alaska, Hawaii, and outside U.S.A.

V-44 ALL-ELECTRONIC DIGITAL VOLTMETER — 500 readings per second . . . measures DC voltages from ±0.001 to ±999.9 volts . . . input impedance 10 megohms . . . completely automatic . . . output for data logging accessories.

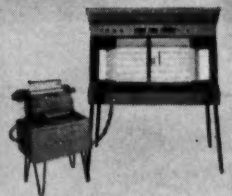
M-24 VOLT-OHM-RATIOMETER — Measures DC voltages of ±.0001 to ±999.9 volts; resistances of .1 ohm to 1 megohm; DC voltage ratios to ±.9999 . . . transistorized completely automatic . . . connectors for data logging accessories . . . complete — $4950.



MODEL 125 AC TO DC CONVERTER — Adds AC voltage ranges to NLS DC digital voltmeters. Ranges, 9.999/99.99/999.9 volts. Frequency range, 10 cps to 10kc . . . Input Impedance, 10 megs shunted by 20uuf . . . exceptional stability . . . complete — $1200.

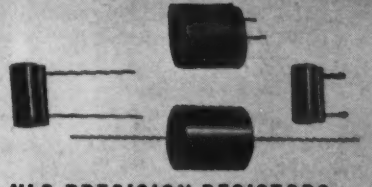
V-35 TRANSISTORIZED VOLTMETER — Measures DC voltages from ±0.0001 to ±999.99 volts, DC voltage ratios to ±.99999 . . . completely automatic . . . plug-in stepping switches . . . 5-digit illuminated readout . . . complete — $4450 (4-digit V-34 also available — $3150).

NLS 481 LOW-COST INDUSTRIAL VOLTMETER — Measures and displays DC voltages of ±0.001 to ±999.9 volts . . . automatically selects and indicates range and polarity . . . 4-digit illuminated readout . . . one compact unit, 5¼-in. high . . . complete — $1285.



NLS 12 "OTRAC" — Semi-automatic oscillogram trace reader and computer . . . permits tabular recording in sequence of digital values of 10 or more traces . . . new optigraphic reading head . . . centralized controls . . . quick-change data handling system.

NLS 50 GO/NO-GO VOLTAGE COMPARATOR — Instantly gives go/no-go indication of voltage level within range of ±0.001 to ±999.9 volts . . . 50 milli-second operating time . . . limit settings to ±0.01% . . . transistorized for highest reliability . . . 3½-in. high.



NLS PRECISION RESISTORS — Vacuum encapsulated in special epoxy resin . . . extremely reliable wire-wound precision resistors of 1 ohm to 5 megohms . . . meet MIL-R-9444 specifications and MIL-R-93 saltwater immersion tests . . . operating temperature limits of −55° to +125° C.

non-linear systems, inc.

Originators of the Digital Voltmeter
DEL MAR (San Diego), CALIFORNIA

NLS—The Digital Voltmeter That Works . . . And Works . . . And Works!

CIRCLE 52 ON INQUIRY CARD

Now...Partners in High-Power Electronics... Vibration and High-Intensity Sound Testing!

LING ALTEC

Ling acquires Altec Companies, Inc.!

The acquisition of the Altec Companies by Ling Electronics provides the most experienced and successful combination of talent and facilities available today in high-power electronics.

LING, as one of the largest manufacturers of vibration testing systems (including power generators, control equipment and electrodynamic shakers) is also a major factor in the development and manufacture of high-power sonar systems and VLF communication equipment.

ALTEC, long a leader in loudspeakers, transducers and high-fidelity sound, has led the way in high-intensity acoustic systems.

Together, LING/ALTEC provide matched acoustic systems which extend the range and flexibility of vibration testing to meet the most challenging problems of our age.

ALTEC COMPANIES, INC.
...Leader in high-fidelity sound and high-intensity acoustic systems.

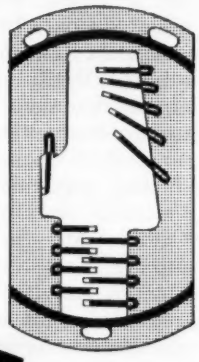
LING ELECTRONICS, INC.
...First in vibration systems and other applications of high-power electronics.

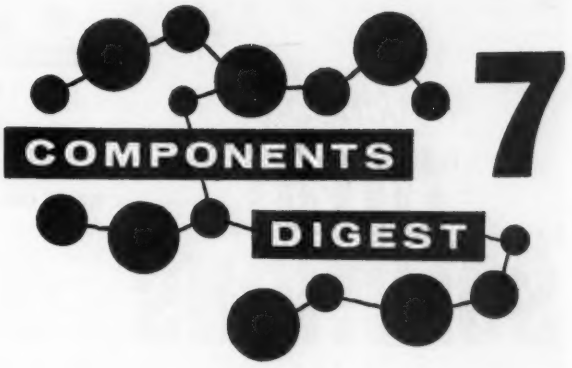
125 Field Engineers Throughout the Nation For Efficient Service!

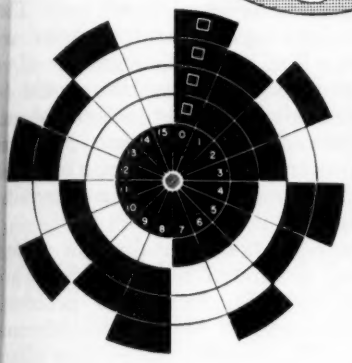
Now...faster, better service for users of Ling and Altec equipment is assured by a new network of service offices. Altec Service Company field engineers in cities from coast-to-coast will assume servicing responsibilities for Ling and Altec products and systems.

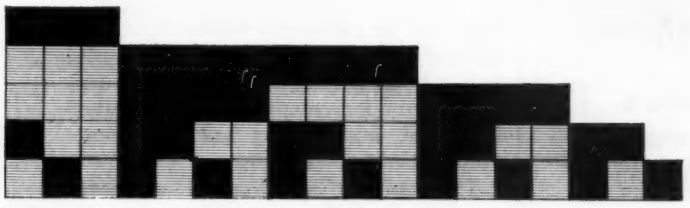
LING ELECTRONICS, INC. 9937 West Jefferson Blvd. • Culver City, Calif. • TExas 0-7711

CIRCLE 53 ON INQUIRY CARD









Analog-Digital Converters

Components Digest No. 7 deals with analog to digital conversion devices. The presentation will be in several parts. Coverage in this part is confined to shaft angle encoders of the brush type that generate digital output as a function of shaft position. Part II to be included in the July issue will cover shaft angle encoders of the optical type, encoders with voltage input, a survey of commercial encoders, and a buyers' guide.

A large portion of Part I is taken from a text published early in 1958 jointly by the Technology Press of Massachusetts Institute of Technology and John Wiley and Sons, Inc. This text "Notes on Analog-Digital Conversion Techniques," edited by Alfred K. Susskind, constituted the basis of Summer courses in 1956 and 1957 at M.I.T. Chapter VI of the book, by John E. Ward, applies so directly to the introductory theory portion of this Components Digest that we have taken material from it freely, with modification to suit our magazine format. Additional valuable material was contributed by John Cronin of Librascope and Ken Bacon of Norden Laboratories. Many manufacturers contributed specialized information on their products, and these will be credited where this material is referenced, principally in Part II.

Devices for obtaining the digital representation of a linear displacement or an angular rotation are called *position coders.* They are a relatively new class of mechanical-to-electrical "transducers" which ultimately deliver not a proportional electrical analog signal as most transducers do, but a set of two-level signals which represent the digits in a number. The primary advantages of such devices are that they: (a) provide a means for communication between mechanical systems and digital data-handling systems, and (b) open new horizons on the accuracy and resolution of the electrical representation of mechanical motion.

Classification

Position coders may broadly be divided into two types depending on whether a continuous or a quantized transducer is used. In the first of these, the physical motion is first converted to a proportional electrical quantity or time interval by means of an appropriate continuous transducer (e.g. a potentiometer), and conversion to digital form is then performed by a voltage or time coder. In such a system, the characteristics of the transducer must be considered with those of the cascaded voltage or time coder to determine the over-all characteristics of the conversion system. Most position coders of this type make use of standard transducers such as potentiometers, resolvers, and synchros which have long been used in measurement and control systems. However, recent interest in increased accuracy and resolution for position coders has led to new developments in these "standard" transducers. There are also new types of continuous transducers appearing which are perhaps better suited to digital conversion. One example is a transducer which utilizes a vibrating string, the frequency of which can be made proportional to various quantities such as acceleration, temperature, *etc.* The output of such a transducer is easily coded.

In the second type of position coder, the physical motion is subdivided into incremental motions by a special quantized transducer, and conversion to digital form is accomplished by determining the number of increments contained in a particular motion. This second type has two important subtypes: (a) devices in which successive increments of position are indistinguishable and must be counted, and (b) devices in which successive incremental positions are coded (numbered) so that the number corresponding to any posi-

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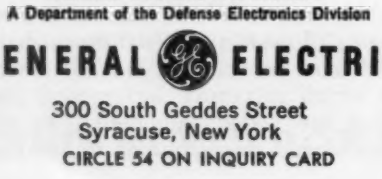

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ANALOG-DIGITAL CONVERTERS

tion can be determined directly. In the *ncremental pattern* devices (first subtype), the output of the transducer is the same for each quantized position and we ask, "How many of these basic increments does it take to add up to the total motion observed?" This question can be answered either by completely recounting each time the position is to be coded, or by remembering how many increments there were the last time, and adding or subtracting only the recent changes.

The devices with *coded patterns* (second subtype) are directly analogous to a scale or ruler, and it is only necessary to read the code at the current position. No further counting or coding operations are necessary, although the code may later have to be converted to another form for a particular use.

General Remarks on Transducers

A motion converter can be no better than the basic transducer it uses to produce electrical signals equivalent to a physical motion, or vice versa. All transducers make use of information stored in some manner in a physical medium. The limitations on the quality of the stored information in continuous transducers, such as a potentiometer or synchro, are well known. Limitations on the newer quantized transducers in which the information is contained in the increment markings stored in a commutator, optical mask, or magnetic structure are not quite as well known, however. It is interesting to investigate the nature of this stored information in various devices so as to understand better the limitations of each device, and to point the way for future development.

Many physical principles can be used to make a pattern that can "read" by automatic means. Methods currently used are electrical contacts (commutator and brushes), patterns which control the transmission or reflection of optical energy, and magnetic devices. Magnetic pattern devices may use homogeneous magnetic media, such as a magnetic drum to store an information pattern of magnetized spots, or may use a fixed magnetic structure determined by winding patterns and/or pole shapes. Each of these methods has physical limitations which affect its usefulness as a motion converter.

In commutator devices, there is a definite limit to the resolution that can be achieved, because brush contact areas can only be reduced to a certain point. At the present time, a brush width of 0.005 inch is considered to be about minimum, and the narrowest usable commutator segment width is about 0.020 inch. Thus, about 300 conducting segments can be placed on a practical four-inch diameter disc. Commutators for position coders are usually made by a photoengraving process, and the accuracy with which segment edges can be controlled in manufacture is about 0.005 inch. This places an upper limit on coder accuracy. For example, segment edges in a four-inch diameter disc would be accurate to about eight minutes of arc. However, brush alignment problems will prevent this level of accuracy from actually being reached in a commutator coder.

The resolution in reading an optical pattern is limited only by the wave length of light. Defraction problems do not begin to become troublesome until a slit is made smaller than about four microns (0.00016 inch), and if diffraction is a problem, monochromatic light of very short wave length can be used. A typical optical pattern made by photographic techniques has 16,384 opaque segments in a nine-inch diameter. The segments are approximately 0.0008 inch wide, and a four-micron reading slit can be used. Even greater line densities have been achieved. Thus, it is seen that the resolution of reading optical patterns can be as much as 30 times that of an electrical commutator. Also, the segment edges in an optical pattern can be controlled more accurately in manufacture by about an equal factor. Present photoelectric ruling engines have an accuracy of better than two seconds of arc. At the present state of the art, the highest obtainable accuracy of optical patterns and associated reading methods is about 1 part in 100,000, far better than that of potentiometers, electrical commutators, and magnetic devices used as coded pattern generators.

Shaft Position Encoders

The shaft position-to-digital encoder provides the most direct means of expressing a shaft angle in digital terms. Encoders are available with either linear or functional outputs, and in many output binary codes, each having some advantage in specific applications. Shaft encoders are *quantizers*, converting a smoothly varying function (shaft angle) into discrete values (digits), the number of digits depending upon the desired resolution. Since the number of discrete values that can be expressed numerically is finite, a digital expression is always approximate.

Operation

The most common means of translating a shaft angle into a digital code is through an arrangement of pick-off brushes, or an optical equivalent, and shaft-driven discs with conducting surfaces arrayed in suitable patterns. The patterns consist of concentric tracks, each track representing a binary digit. The least significant digit track is at the circumference, with more significant tracks displaced toward the center. The most significant digit is represented by the innermost track.

Each track is divided into *segments*, which provide either a conducting or a non-conducting path to the brush (or optical) contact (s) associated with the track. The angular span of the individual segments of the track is determined by the significance of the digit.

For the *least* significant digit

$2^{(N-N)}\ 2^N/360° =$

Segment span in degrees,

where N is the number of binary digits expressed by the disc.

And for the most significant digit,

$2^{(N-1)}\ 2^N/360° =$

Segment span in degrees.

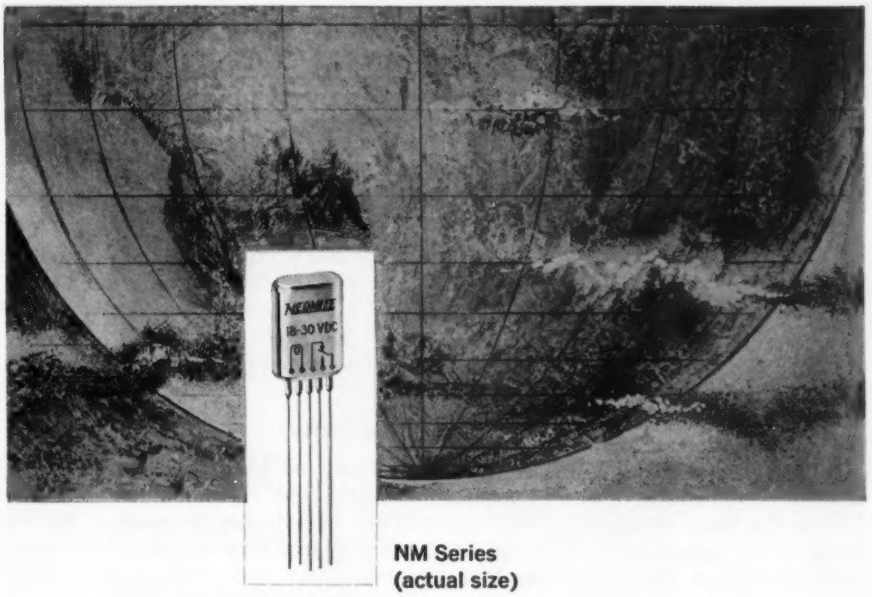
The most significant digit track contains segments 180° long; successive tracks in the direction of decreasing significance contain segments whose lengths are successively half as long as on preceding tracks. Segments are alternately conducting and non-conducting, corresponding most commonly to binary 1 and zero respectively.

Means of Reading Discs

Commercially available encoders are primarily read by either sliding brush contacts, or photo-electrically. The two methods are not competitive, but rather complementary. Because the sliding brush contacts are easiest to visualize, they will be the method used to illustrate the reading of shaft encoders. Optical read-outs will be described in Part II of this Digest.

Consider an ideal sliding brush of zero width. Place a set of brushes along a radial line, one for each track, and a common brush. The disc, as described, consists of conducting and non-conducting segments arrayed in concentric sets. A brush contacting a conducting segment has electrical continuity to the common brush. Each brush gives an output dependent upon the (conducting or non-conducting) state of the segment that it contacts. The output of the brushes is a binary representation of disc position from a fixed reference. The reference may be considered as the radial line of brushes, or the *index line*.

Non-ideal aspects are now consid-



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ered in order of decreasing importance:
1. Contacts have finite width.
2. Disc patterns have inaccuracies.
3. Brush alignment cannot be perfectly maintained during encoder life.
4. Concentricity errors occur between disc and shaft.
5. Bearings exhibit geometric errors.

Ambiguity

Because of inevitable inaccuracies as listed above, a fundamental problem arises of output ambiguity at the transition points between digits. In the natural binary code, for example, it frequently happens that more than one binary digit (or bit) will change in going from one number to the next. Since the pick-up brushes cannot change exactly simultaneously, there occur narrow intervals of partial transition where some, but not all, brushes have made the next contact. The numbers corresponding to these partial transition conditions do not necessarily interpolate between the pair of numbers represented by the brush contacts before and after the transition. As a result, a "random" series of numbers may occur between successive outputs, which can impair the value of the converter. In some applications the difficulty is averted by reading out only for discreet shaft portions corresponding to nonambiguous conditions. But this is not sufficiently general.

The more general approach may take either of two directions: development of special binary codes which change only one digit at a time, such as the familiar Gray code, and by additional brushes, selected by logical circuitry to avoid ambiguity. The principal disadvantage of the Gray code is the need to reconvert to natural binary or some other convenient code before use in digital equipment.

The second solution is sometimes called "V scanning" due to the "V" pattern of the physical arrangement of brushes. V scanning calls for two brushes per track on all tracks but the least significant. One of the two brushes is selected to be read through the operation of logical circuitry. In linear converters, V scanning never allows a selected brush any closer to the edge of a segment than 25% of the segment length.

Theory of V Scanning

Earlier it was noted that quantizing introduces an error by converting an infinitely variable function into discrete segments. This error becomes the

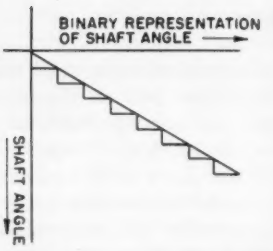

Fig 1 (a) Binary representation of shaft position as generated by encoder.

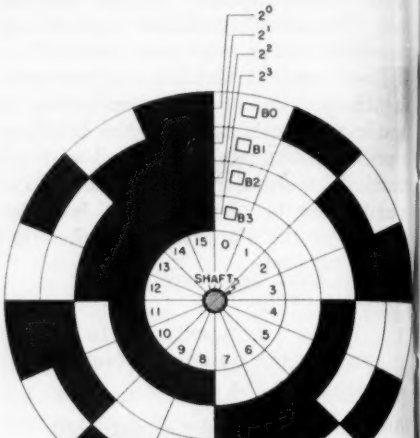

Fig 1 (b) Coding disc.

means of eliminating the ambiguities of reading in true binary code.

Fig. 1(a) shows a linear relationship between shaft angle and its binary representation. The quantizing segments are $360°/2^N$ long. The value of the segment on the encoder is coincident with the function only at the transitions between segments, with errors occurring in other positions. Fig. 1(b) shows a typical disc pattern capable of generating discontinuous output characteristic of Fig. 1(a). The least significant track sets the accuracy of shaft angle conversion at $\pm\frac{1}{2}$ the least significant digit.

To avoid ambiguity, two brushes are placed upon a track, spaced a maximum of one half segment (for the particular track) apart, symmetrically about the index or reading line. This locates them at $\pm\frac{1}{4}$ segment from the index line. These brushes provide an error free reading of a given track when they are "controlled" by a brush from the adjacent track in the least significant direction. Each track in turn is controlled by the next least significant, and the ultimate controlling element is the least significant brush. The rules for brush selection are given below, and illustrated with an extensive description on Fig. 2.

1. When the controlling brush changes from 1 to 0 generating a carry, select the leading (circled) brush in the

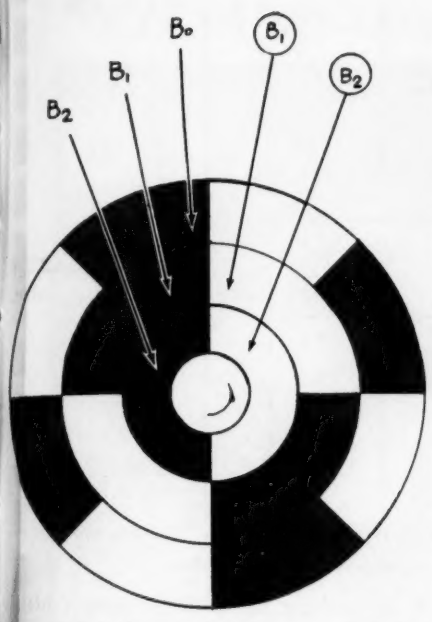

Fig 2 (a) Simplified diagram for description of V scan.

next track.

2. When the controlling brush changes from 0 to 1 select the lagging (plain) brush in the next track.

With these conventions, the brushes provide unambiguous binary representation of shaft angle without regard to direction of shaft rotation. Only the LSD (least significant digit) brush, B_0 is read at a transition; all others are read only in the middle 50% of the segment widths, converting shaft angle to unambiguous binary code within the limits of the quantizing error of $\pm$ ½ LSD value.

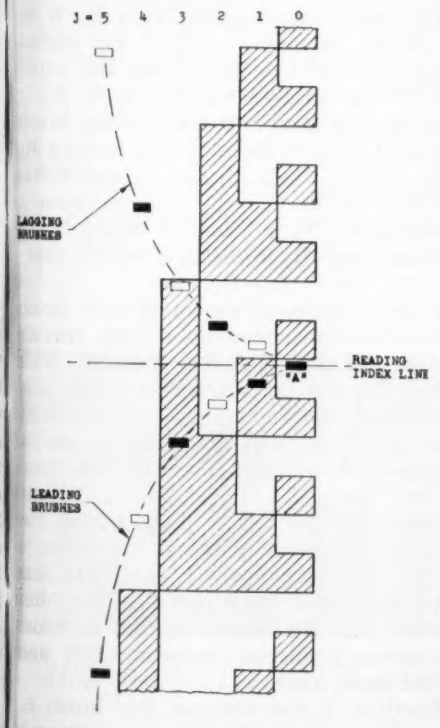

Fig 2 (b) V-Brush reading method, more detailed layout. The exponential V pattern is evident in this figure.

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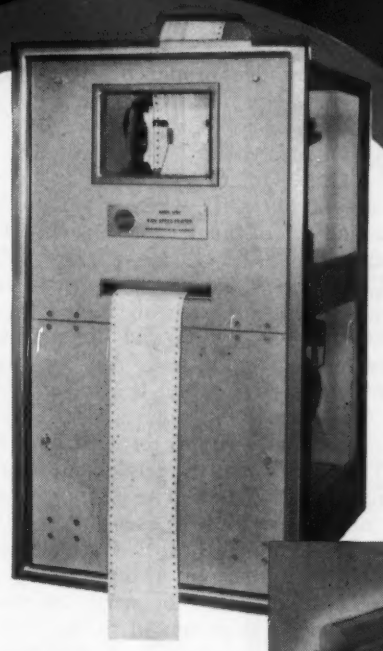

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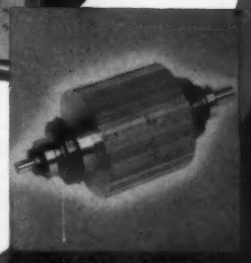

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Brush Selecting Logic

The logic required to provide proper brush selection for V scanning consists of:

Two "And" Gates
One Inverter
One "Or" Gate

per binary digit except the LSD which is inherently unambiguous. These logical elements are normally external in this type encoder.

NOTE: An "And" Gate has two or more inputs and one output. The output is 1 only when all inputs are 1. An "Or" Gate has two or more inputs and one output. The output is 1 whenever any input is 1. An "Inverter" has one input and one output. The output is always the inverse of the input, i.e., 0 in, 1 out.

The logic is arranged as in Fig. 3 for a parallel encoder output. The "And" Gate serving the circled number B_1 receives 1 input from the inverter. The 0 input from the associated brush inhibits the Gate presenting an 0 output to the "Or" Gates. The other "And" Gate serving the plain number B_1 is presented an 0 input from the B_0 brush and is inhibited regardless of what its associated brush reads; so a second 0 is presented to the "Or" Gate. The "Or" Gate output is an unambiguous 0 and is represented on the B_1^* line. Operation of the B_2^* digit is identical.

Note that the brushes are displaced in the first segment so that brush B_1 is on the transition between 1 and 0. The logic prevents B_1 from reading in this region. As the code pattern passes beneath the brushes, B_0 makes the transition from 0 to 1 and the logic prevents brush circled B_1 from reading.

Self-Contained Logic Elements

The preceding discussion has shown that one of a pair of brushes in each zone, progressively staggered farther and farther from the reading index line, can be logically selected so as to prevent reading ambiguities. In the simple V-brush scheme discussed, however, external switching circuits are required to select the brushes in sequence, with each decision based on the reading in the next less significant zone. It is possible to make the disc itself perform the required switching by adding two additional

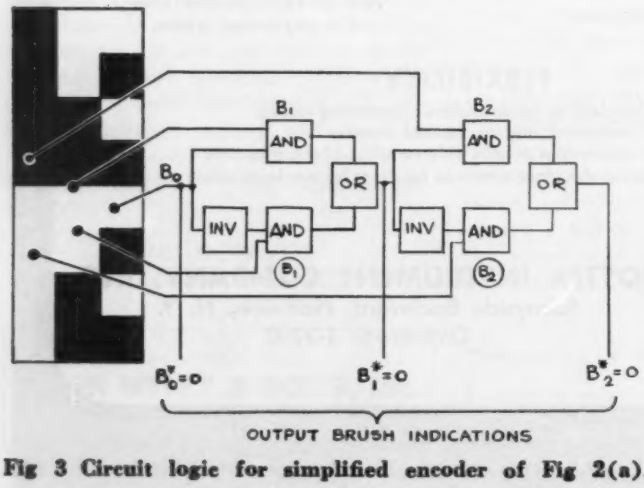

Fig 3 Circuit logic for simplified encoder of Fig 2(a).

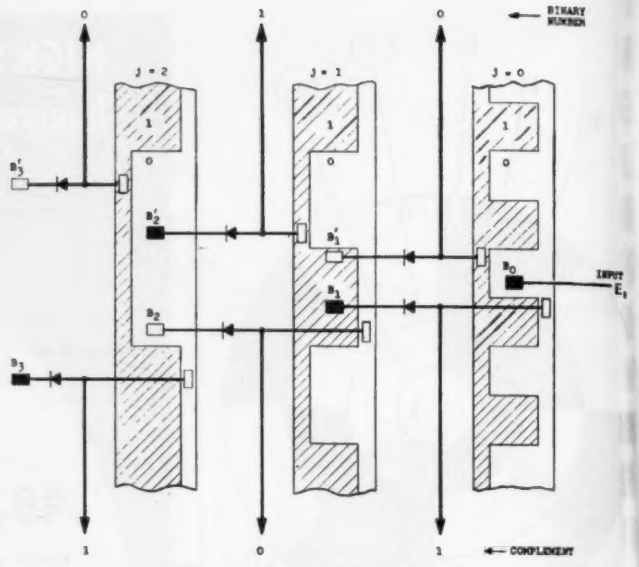

Fig 4 Self-switching V-brushes

brushes per zone and by making the code pattern a little differently.

Three digits of a self-switching V-brush coder are shown in Fig. 4. It will be noted that the shaded segments representing ONE's form the usual binary commutator pattern, with the exception that the segments in each zone are connected together, but not to the segments of any other zone. In this case, the intervening white spaces are also electrical contacts representing ZERO's and are connected together in each zone, but not from zone to zone. The white and shaded segments are insulated from each other and are binary complements. It will also be noted that the brushes B_0, B_1, B'_1, B'_2 are placed in the same V pattern which was shown in Fig. 3. Brushes B_1, B_2, etc. are leading, and B'_1, B'_2, etc. are lagging.

To understand the operation, assume for the moment that brush B_0 is ideal and can switch instantaneously from a white to a shaded segment in zone 0. It will be seen that voltage E_1 will be applied to the leading brush in zone 1 if B_0 is on a ZERO, and to the lagging brush B'_1 if B_0 is on a ONE. The brush voltages in zone 1 are picked up from the slip rings connected to the shaded and white segments in zone 0. In the case shown in Fig. 4, B_0 is on a ZERO in zone 0, and therefore the leading brush B_1 is energized in zone 1. This is indicated by making B_1 solid black. Brush B_1 is on a ONE in zone 1, and therefore the voltage picked up by the slip ring in zone 1 energizes the lagging brush B'_2 in zone 2. Since B'_2 is on a ZERO, the leading brush B_3 in the next zone is energized, and so forth.

It is necessary to insert diodes as shown in each brush lead in order to prevent incorrect readings if both brushes in a given zone are on the same segment. In zone 1, for example, both B_1 and B'_1 are on a ONE segment, and if the diodes were omitted, the voltage injected by brush B_1 would be picked up by B'_1 and sent back as an incorrect reading for zone 0. The diodes block all such feedback paths.

Note that the outputs at the top of Fig. 4 give the binary number (010 for the brush positions shown) and the bottom outputs give its complement (101). Note also that a brush is never used whenever it is within the outer quarters of a segment, and the segments can therefore be shortened for generous insulation between ONE and ZERO segments in the same zone.

In the above explanation, it was assumed that brush B_0 was perfect and would have no ambiguity in selecting a ONE or a ZERO segment in zone 0. Actually, a simple brush and segment arrangement will not meet this re-

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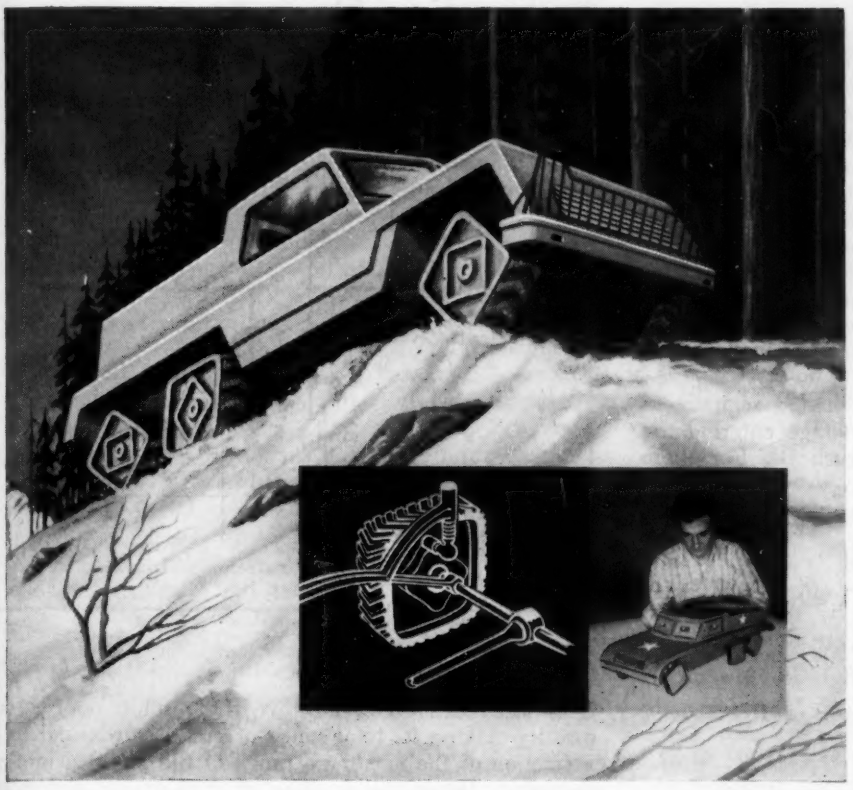

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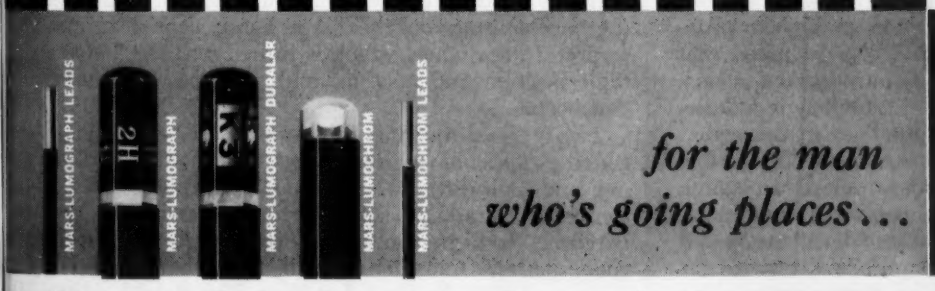

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quirement, and it is necessary to eliminate the white set of segments and the associated slip ring and brush for zone 0 shown in Fig. 4, and use an external decision circuit to select B'_1 if B_0 is on a shaded segment, and B_1 if it is not. This decision circuit serves exactly the same function as the brush selectors in the simple V-brush scheme, and can be any sort of bi-stable element switched by a voltage applied to the segments of the first zone and read by brush B_0. It is also possible for certain uses to provide the required switching function with the aid of only four resistors which can be located in the coder. The operation of this simple decision circuit is illustrated in Fig. 5.

When brush B_0 is not contacting a shaded segment in zone 0 as shown in Fig. 5, the only voltage entering the coder is E_2, which is injected into brush B_1. For these conditions, E_2 is equal to

$$E_{2(\text{ZERO})} = E[R_3/(R_1 + R_2 + R_3)]$$

This voltage appears as a ONE on the complement line for zone 0. When brush B_0 is on a shaded segment in zone 0, the resistor network is altered by the connection of R_4 from E_1 to ground. The voltages are then:

$$E_{1(\text{ONE})} = ER_Z/(R_1 + R_2)$$

$$\text{where } R_Z = R_4(R_2 + R_3)/(R_4 + R_2 + R_3)$$

$$E_{2(\text{ONE})} = E_{1(\text{ONE})}[R_3/(R_2 + R_3)]$$

The above switching action satisfies the requirements because when there is a ZERO in zone 0, voltage is applied only to the leading brush B_1 in zone 1. When brush B_0 is on a ONE segment, voltage $E_{1(\text{ONE})}$ injected into brush B'_1 is more positive than $E_{2(\text{ONE})}$ by the ratio $(R_2 + R_3)R_3$. If the resistors are properly chosen, voltages $E_{1(\text{ONE})}$ and $E_{2(\text{ZERO})}$ are both larger than voltage $E_{2(\text{ONE})}$ and a discriminator can be used in each number output or complement output line to give ONE outputs only for voltages $E_{1(\text{ONE})}$ and $E_{2(\text{ZERO})}$. For example if there are no output loads and R_1 is made twice as large as R_2, R_3, and R_4, $E_{1(\text{ONE})}$ and $E_{2(\text{ZERO})}$ are equal, and twice as large as $E_{2(\text{ONE})}$.

An advantage of the self-selecting reading method is that the brushes and the code pattern constitute the entire reading circuitry and the coder can be completely self-contained (except for an external input decision unit). Another advantage is that both the binary number and its complement can be read directly from the coder, making it possible to change the direction of the count if desired, i.e., to obtain increasing numbers for CW or CCW rotation.

A possible disadvantage of the self-selecting coder is that the pattern is more complicated to make, and four brushes are required per zone. Friction and wear problems may thereby be increased. It will also be noted that the forward resistance of one diode is introduced for each zone, and thus the voltage on any output line is a function of the currents in all other output lines in the coder. The ONE and ZERO voltages on a given output line varies with the position of the coder, unless very high impedance input circuits are used in associated equipment, or unless the number and the complement lines are loaded equally. In the latter case, signal amplitude decreases for the more significant digits.

Although the V-brush principle could be applied to optical coders, the difficulties of photocell and slit alignment in a V arrangement have restricted its use to date to commutator coders. Obviously, the self-switching V-brushes cannot be used in optical reading.

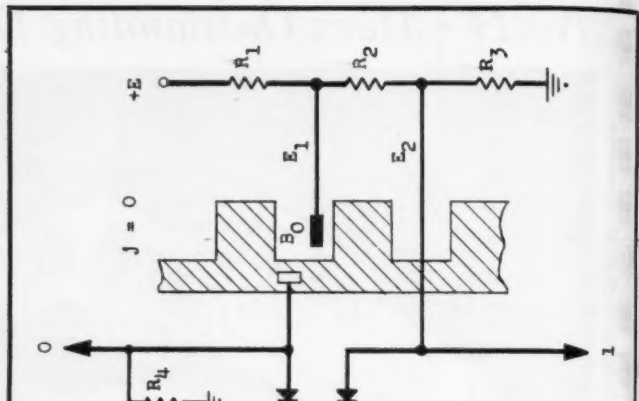

Fig 5 Resistor decision circuit

Multispeed Binary Coders

It is often desired to improve the resolution of a coded disc by making its total range of codes correspond to only a fraction of the maximum range of the physical motion to be coded. When this is done, it is of course necessary to account in the digital number for the number of complete code cycles required to reach a given position. This is analogous to the requirement that an incremental pattern count position increments, except that it is usually desired that the transducer itself provide the cycle count along with the reading of the code disc. In coded-disc devices, this is accomplished by providing one or more additional coded discs, each geared to turn at a slower speed than the one preceding it. All patterns can then be read simultaneously to obtain the total digital number. To reach the total count in such a coder, the input shaft must be turned through a number of revolutions equal to the count on all the "slow" discs. Therefore, the adjectives multitum or multispeed have been applied to these coders.

A common example of a multispeed coder is an automobile odometer. In such a transfer-type decimal counter, the rotation of a digit wheel between the digits nine and zero is used to transfer a one-digit motion to the next significant wheel, and there is, therefore, a transition range in which a number of wheels can be in process of changing by one digit at the same time. For visual reading, this situation is not troublesome, since the reading can be correctly interpreted by a human observer. Simple switching mechanisms, on the other hand, cannot properly interpret a digit wheel which is turned partially between one digit position and another, and gross reading ambiguities can occur.

Two general methods for avoiding ambiguity in reading coded patterns have already been discussed: logical switching and unit-distance codes. Of these two, only logical switching affords a solution to the ambiguity problem between discs in multispeed coders. In a unit-distance code, pattern transitions in all zones have equal significance and gear backlash between discs would destroy the coder accuracy, or even the pattern sequence. However, logical switching, as has been demonstrated, permits choosing of one or two brushes in each zone, so that maximum tolerance to errors in location of pattern transitions is obtained.

If a natural binary code is used in a multispeed coder with a disc-speed ratio N, the slow disc is a continuation of the binary pattern, with segments 1/N as wide as they would be on the fast disc and moving past the reading index 1/N times as fast. Thus, either simple V-brushes or self-switching V-brushes may be used without modification. Maximum tolerance of the placement of the brushes, with respect to the optimum position, is ± one-quarter segment. If gearing is now added, this tolerance applies to the combined gearing, brush placement and pattern errors. Hence, it seems reasonable to place a limit of ± one-eighth segment on gearing errors.

A simplified example of a multispeed coder with three digits on each disc (N = 8) is shown in Fig. 6. The position of the fast disc on this coder is the same as the examples in Figs. 2 (b) and 4 and the same reading 010 is obtained. Note that two brushes B_3 and B'_3 are used on the least significant zone on the slow disc which has turned only one-eighth as far as the fast disc. Brushes B_3 and B'_3 are selected by the reading from the most significant zone (brushes B_2 and B'_2) on the fast disc. As shown, zone 2 reads ZERO so the leading brush B_3 is chosen. Since it reads ZERO, brush B_4 is chosen, and it in turn reads ZERO and selects B_5, which also reads ZERO. The total reading in Fig. 6 and the brushes used are as follows:

B_5	B_4	B_3	B'_2	B_1	B_0
0	0	0	0	1	0

By gearing the slow disc to the initial (fast) disc, the total count has been increased from 2^3 (8) to 2^6 (64), and any number of additional discs can be added, with each disc providing an additional factor of 2^3.

Note, however, that the input resolution of the coder itself is not improved. Increased system resolution with this coder is obtained only by providing *step-up* input gearing to the coder, so that one quantum on the fast disc represents a smaller increment of the physical motion being coded.

Perhaps the most obvious advantage of a multispeed coding device is that the very small dimensional tolerances of single-turn discs can be avoided and disc-manufacturing problems are therefore reduced. For example, several thirteen-digit coders are available with a seven-digit fast disc and a six-digit slow disc, geared together through a 64:1 gear train. The fast disc counts to 2^7 (128) per revolution, and the slow disc counts to 2^6 (64) revolutions of the fast disc. The total count for 64 revolutions is therefore 2^{13}, or 8,192. It is much easier to produce six-digit and seven-digit commutator discs than it would be a single thirteen-digit disc; in fact, as will be discussed, a thirteen-digit single-turn commutator of reasonable diameter cannot be manufactured by present methods.

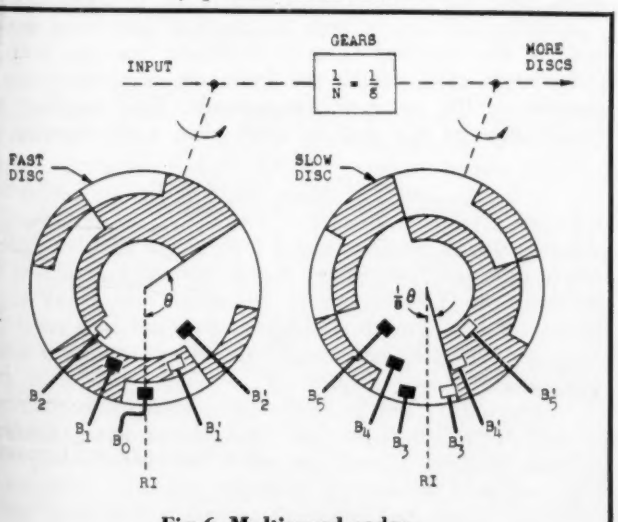

Fig 6 Multispeed coder

A second advantage of the multispeed coder is that the diameter is reduced for a given count. Since so few segments are required per disc, the two discs in the thirteen-digit converter can be made about an inch in diameter. If desired, an additional 64:1 gear train and six-digit disc can be added to give a total count of 2^{19}, or 524,288 with no increase in diameter.

The disadvantages of a multispeed coder may be seen by comparing the multispeed coder to a fine-coarse synchro system, in which one synchro is geared-up to improve its resolution, and to reduce the effect of its inaccuracies. A coarse synchro is required for system synchronization if the geared-up synchro makes more than one revolution in the range of measurement. The same gearing problems which are familiar in two-speed synchro systems are also encountered with multispeed coders: input gear errors, increased input speed to the geared-up device, and large reflected inertia of the geared-up unit.

Coupling Coders to Other Components

Coders using continuous or quantized transducers can be manufactured with accuracies ranging from a few seconds to a few minutes of arc. A serious question arises as to whether a transducer can be coupled with these same accuracies to a shaft which is to be measured. Two possible methods of coupling are: to mount the rotating portion of the transducer directly on the shaft that is to be measured; and to use separate bearings for the transducer and then couple its shaft to the shaft to be measured. Both of these methods have certain drawbacks.

The first problem in mounting a coder is play and eccentricity in the bearings. In some optical shaft coders a segment width of 0.0009 inch at a radius of about four inches represents one quantum. Since the reading slit is fixed, translational motion of the disc due to radial play or eccentricity in its shaft bearings can cause errors unless such translations are held to values much smaller than the 0.0009-inch quantum width. Free radial play in the bearing causes random reading errors, depending upon the direction of accelerating forces. In general, errors result only from relative motion of the disc at right angles to the slit, as shown in Fig 7. An eccentricity causes cyclic errors, which are at a maximum when the maximum eccentricity is at right angles to the reading slit, and zero when it is in line with the reading slit.

Suppose that an optical disc is to be mounted directly on the gimbal shaft of a large radar antenna. Since the antenna is large and, therefore, heavy, it has large, heavy-duty bearings that typically have a radial play of one or two thousandths of an inch. Although this amount of radial play in the bearings has a completely negligible effect on the angle between the radar antenna and an object several miles away, it can have a disastrous effect on the relation between a reading slit and the segments in a code disc. Reading errors of five or more digits in a sixteen-digit optical coder might be expected. In situations such as this, it is clearly impossible to mount the disc directly on the shaft which is to be measured.

Errors due to bearing run-out and eccentricity on the shaft to be measured can be alleviated by mounting the disc on its own precision instrument bearings. Even in this case, however, it is still difficult to control bearing eccentricity and play to the extent necessary to avoid all reading errors. Bearing selection is necessary, and special precautions must be taken in fitting the bearings into the coder housing and the coder shaft. In general, it is also necessary to apply an axial preload to the bearings in order to control radial play.

Clearly, a coder disc must be exactly centered on its axis of rotation. Optical disc manufacturers cannot provide

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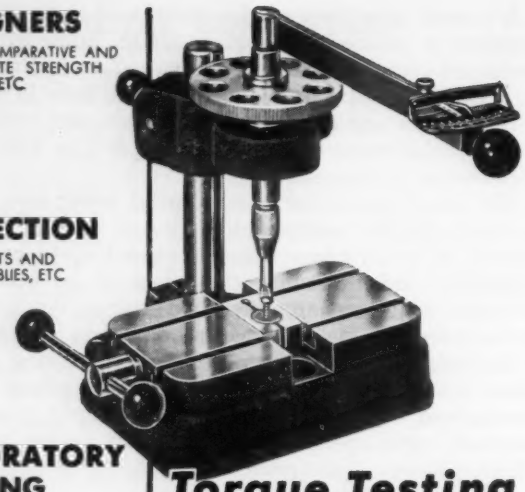

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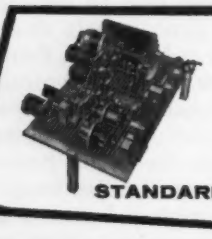

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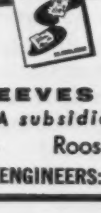

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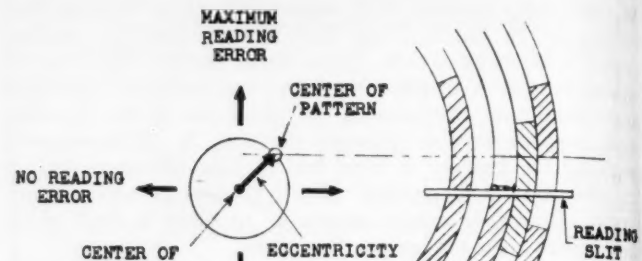

Fig 7 Effect of eccentricity on coded discs

accurate concentric mounting holes in the glass discs to the required tolerances, and it is therefore usual to clamp or cement the disc in place after it has been very carefully centered on the shaft. Centering to 0.0001 inch or better is easily accomplished (provided the pattern is round within the same tolerance) by using a microscope to observe the edge of one of the zones and by gradually tapping the disc until run-out is a minimum.

Once a coder disc has been satisfactorily mounted on its own bearings, the next problem is how to couple it to the shaft that is to be measured. This problem also arises in coupling the continuous transducers, such as synchros, resolvers, and potentiometers. As we have already seen, one of the main reaons for not mounting a disc on the shaft to be coded was to avoid the radial play and eccentricity present in that shaft. This same play and eccentricity will cause damaging loads on the high-precision coder bearings if the two shafts are directly connected. Some sort of flexible coupling is therefore required that can absorb radial bearing play and eccentricity, and axial shaft misalignments, but does not introduce angular errors.

One type of coupling used experimentally with coders is a long, thin flexible shaft sometimes called a quill shaft. The longer the shaft, the better, so far as a reduction of angular coder errors is concerned. The quill shaft, shown in Fig. 8, is effective because the shaft can be bent significantly from a straight line without affecting the relative angle of the shaft ends. Unfortunately, the shaft must be made quite thin and flexible to obtain low bending forces, which also reduces the torsional stiffness and therefore the natural frequency of the shaft-coder combination. The coder coupled with a flexible shaft therefore tends to have an oscillatory response to sudden changes in the input shaft, and significant errors under dynamic conditions.

A more satisfactory type of coupling has been worked out by the Farrand Optical Company for use with its Inductosyn units, which are harmonic resolvers with accuracies of the order of five seconds. This coupling is a modification of the flexible shaft idea, with superior tor-

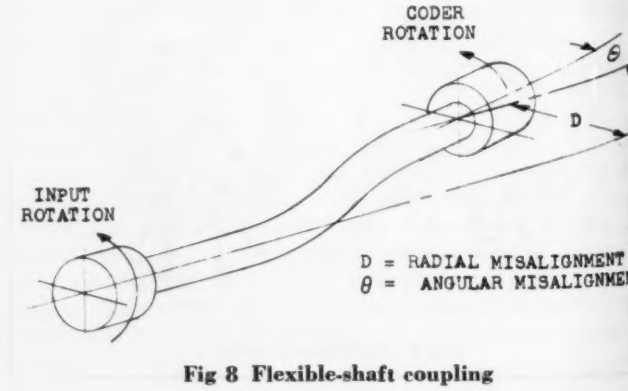

Fig 8 Flexible-shaft coupling

sional stiffness. Two spring bellows couplings are used, separated by sections of tubular shafting as shown in Fig. 9. Although a simple bellows coupling is as subject to angular errors from shaft misalignment as any other type, the incorporation of the two tubular sections (between the input shaft and the first coupling, and between the two couplings) reduces the amount of angular distortion that must be absorbed by each bellows. In the Farrand coupling, too, very careful attention has been paid to the bellows design, and it is stated that the complete coupling can absorb up to 0.002 inch of the radial play, and up to five minutes of arc in angular misalignment of the two shafts, without introducing an angular error larger than a few seconds of arc.

Position coders have higher accuracy and resolution

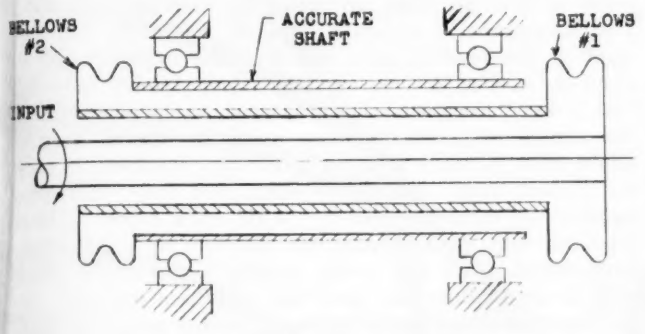

Fig 9 Farrand bellows coupling

than many other devices the engineer has been accustomed to using, such as synchros and potentiometers. Although only coders of high resolution require the extreme care in mounting and coupling that has been discussed, coders of any type always need careful coupling.

In selecting a shaft position encoder, it is helpful to consider the following items:

1. Choice of code (this is often dictated by application considerations).

A. Binary is the most economical in terms of hardware, and most widely used in computers. Binary code predominates in shaft encoders.

B. Binary-coded-decimal. Several versions of codes that translate easily to decimal are used. The code, in most general use is not as economical of hardware as binary, but its ease of conversion to decimal makes it desirable where human monitoring is necessary or where printed records are needed.

C. Gray Code. This is inherently unambiguous. Techniques which eliminate ambiguity in direct binary translation from a shaft angle are reducing its importance. However, it is the universal language of photoelectric encoders.

2. Serial or parallel output. This depends upon the associated equipment. Self selecting encoders or those which operate in Gray Code are characteristically parallel in output. Encoders which utilize external brush selection techniques are serial in output.

3. Function. In the majority of shaft encoders, output is related to shaft angle in a linear manner. Many encoders are available, however, which relate shaft angle to a nonlinear function, algerbraic, transcendental or empirical. The most common type available is the sine/cosine encoder whose output is the binary representation of the sine function at a shaft angle θ. These may use V scanning to eliminate ambiguities. Sine and cosine outputs may be available continuously and independently. One turn of the input shaft causes these encoders to generate 360° of information. The use of discs to encode functions such as the sine and cosine is desirable because of the large saving in computer time.

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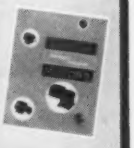

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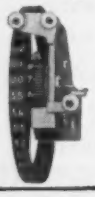

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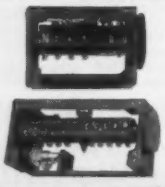

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A host of factors influence life. The principal errors stem from noise—electrical or optical. Noise reduces the ability of the encoder to distinguish between two binary states. The encoder interrogation period relates directly to reliability. In high speed computers the time spent looking at encoder output may be less than one microsecond. If this interrogation pulse should occur during a noise pulse of like duration, an erroneous reading may occur. The occurrence of an error depends upon the time constant of the reading gate and the time-amplitude of the noise pulse. For this reason the longest possible interrogation pulse is recommended. Extreme care is exercised by the manufacturer to eliminate noise. In optical encoders where dust particles and pin holes can contribute to noise, the manufacturer thoroughly eliminates these difficulties, maintaining maximum density of the dark areas. In brush type encoders the manufacturer carefully selects the stock from which discs are made, usually a laminated plastic with a conducting foil. Both foil and base material must be free of pits and imperfections. The disc pattern is transferred to the conduction foil by a photographic process, after which the board is placed in an etching tank where unexposed areas are removed. Depending upon the foil, auxiliary layers of conducting materials may be plated on to give desirable electrical characteristics to the surface. After plating the etched pattern is heavily pressed into the plastic base to eliminate mechanical discontinuities between conducting and non-conducting areas. These are less than 0.0001″ after the pressing operation.

The brush material is normally noble metal alloy chosen for good commutating characteristics. Proper brush tension and precise mechanical assembly also contribute to a reliable encoder.

Part II of Analog-Digital Converters, to be included in our July issue, will cover theory, design and selection of voltage-to-digital converters and optical shaft angle encoders. Summary manufacturer's data and buyers' guides for all classes of converters will conclude the section.

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